# APPLICATION OF EXERGY ANALYSIS METHOD TO ENERGY EFFICIENT BUILDING BLOCK DESIGN

**A Thesis Submitted to**
**the Graduate School of Engineering and Sciences of**
**İzmir Institute of Technology**
**in Partial Fulfillment of the Requirements for the Degree of**

**DOCTOR OF PHILOSOPHY**

**in City and Regional Planning**

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**March 2014**
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# ACKNOWLEDGEMENTS

Initially I offer my sincerest gratitude to my supervisor, Assist. Prof. Dr. Nicel Saygın, who has supported me throughout my thesis process with her valuable knowledge and expert guidance. I would also like to thank the members of the thesis defense committee, Assoc. Prof. Dr. Semahat Ozdemir and Assoc. Prof. Dr. F. Zehra Ozçelik for inspiring discussion and comments.

I also sincerely thank to Prof. Dr. İbrahim Dinçer, especially for his support and guidance in the decision of the thesis title and content.

Finally, it is a pleasure to thank to my family, especially my husband S. Orçun Mert, and friends for their help, emotional support and encouragement they provided, and for their great patience and love.

# ABSTRACT


## APPLICATION OF EXERGY ANALYSIS METHOD TO ENERGY EFFICIENT BUILDING BLOCK DESIGN

This dissertation introduces the exergy analysis method into urban planning field in order to find out the amount of energy that can be conserved in a building block when energy efficient design is applied. Two hypotheses are developed here: 1. Exergy analysis is a suitable tool for the built environment, and 2. Energy efficient design parameters provide energy saving in the built environment. A case study approach is undertaken in order to test the hypotheses stated above. To do this, first, the energy efficient design parameters have been derived from the literature and design alternatives are developed accordingly; second, data has been gathered from the case area for the exergy calculations; third, exergy analysis of existing building blocks and proposed design alternatives are carried out, and finally, the amount of decrease in the exergy loss due to energy efficient design is found out.

The findings in this study show that the exergy efficiency of the existing building blocks is nearly 2 %, while the proposed design alternatives are nearly 10-11 %. The overall exergy loads of the alternative plans are found as 166.3W, 225.1W, 142.5W, 137.8W and 184.8W respectively for winter and 105.4W, 140.0W, 89.9W, 86.3W and 125.3W respectively for summer on a housing unit basis. These results are much better when compared to the existing situation per housing unit which is 1079W (winter) and 1173W (summer). The best alternative energy efficient planning and design brings 1631 W (winter) and 2810W (summer) of exergy saving that corresponds to 799 TL/year and 978 kg/year reduction in $CO_2$ greenhouse gases emission per housing unit. This data shows that the expected results and are in harmony with the literature. As a result, the suitability and importance of the exergy analysis on the built environment is proved by revealing the energy conservation and sustainable use of energy through using energy efficient design parameters.

# ÖZET

## EKSERJİ ANALİZİ METODUNUN ENERJİ ETKİN YAPI ADASI TASARIMINA UYGULANMASI

Bu çalışmanın amacı ekserji analizi metodunu planlama yazınına kazandırarak enerji etkin tasarım yoluyla bir konut adasında ne kadar ne kadar enerji kazanımı sağlanabileceği ortaya çıkarmaktır. Tezin iki hipotezi bulunmaktadır: 1. Ekserji analizi yapılı çevre için uygun bir araçtır, 2. Enerji etkin tasarım kriterlerini kullanarak yapılı çevrede enerji tasarrufu yapılabilir. Bu hipotezlerin doğruluğunu sınamak için bir çalışma alanında uygulama yapılmıştır. Bunun için öncelikle literatürden enerji etkin planlama kriterleri bir araya getirilmiş ve bunlara göre tasarım alternatifleri oluşturulmuştur. İkinci olarak çalışma alanından gerekli veriler toplanarak mevcut durum ve geliştirilen tasarım önerileri için ekserji analizi yapılmıştır. Son olarak ta enerji etkin tasarım yoluyla engellenen ekserji kayıpları ortaya çıkarılmıştır.

Hesaplamalar sonucunda mevcut alanın ekserji verimliliği 2% olarak bulunmuş, buna karşılık önerilen tasarımların verimliliği 10-11%'lere ulaşmıştır. Birim konut açısından bakıldığında kış dönemi için ekserji yükü sırasıyla 166.3W, 225.1W, 142.5W, 137,8W ve 184.8W yaz dönemi için ise 105.4W, 140.0W, 89.9W, 86.3W ve 125.3W olarak bulunmuştur. Bu değerlerin mevcut durum olan 1079(kış) ve 1173W (yaz) değerleri ile karşılaştırıldığında oldukça iyi olduğu görülmektedir. Sonuç olarak yapılan enerji etkin tasarım yoluyla 1631kW (kış) ve 2810W (yaz) ekserji tasarrufu yapılabileceği ortaya konmuştur. Bunun yanı sıra, 799 TL/yıl oranında bir maliyetten ve 978kg/yıl oranında da bir sera gazı olan $CO_2$ salınımı engellenmiş olacaktır. Bu değerler sonuçların literatür ile uyumlu olduğunu göstermektedir. Sonuç olarak enerji etkin parametrelerin kullanımıyla enerji korunumu ve sürdürülebilir kullanımı ortaya çıkarılmış ve buna bağlı olarak da ekserji analizinin yapılı çevrede kullanılmasının uygun ve önemli olduğu kanıtlanmıştır.

*To my mother Fatma and my daughter Yağmur…*

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# LIST OF SYMBOLS

| | |
|---|---|
| A | Area, $m^2$ |
| $A_N$ | Floor Area of the Building, $m^2$ |
| $C_p$ | Specific Heat, kJ/kgK |
| Ex | Exergy, J, kJ |
| $\dot{E}x$ | Exergy Rate, W, kW |
| $F_f$ | Window Frame Fraction |
| g | Gravitational Acceleration , $m^2/s$ |
| H | Enthalpy, kJ |
| $I_s$ | Solar Radiation, $W/m^2$ |
| $\dot{m}$ | Debi, kg/s |
| $n_d$ | Air Exchange Rate, $m^3/h$ |
| $n_o$ | Number of Occupants |
| $n_v$ | Efficiency Constants |
| P | Presure, atm, bar |
| S | Entropy, J/K |
| T | Temperature, K |
| t | Time, s, h |
| U | Internal Energy, kJ |
| U | Overall Heat Transfer Coefficient $W/m^2K$ |
| V | Speed, m/s |
| V | Volume, $m^3$ |
| $\dot{W}$ | Power, kW, W |

**Greeks**

| | |
|---|---|
| $v$ | Stoichiometric Coefficient |
| $\eta$ | Efficiency |
| $\rho$ | Density, $kg/m^3$ |
| $\Phi_{I,e}$ | specific internal gains of equipment, $W/m^2$ |
| $\Phi_{I,o}$ | specific internal gains of occupants, W/occupant |

**Subscripts**

| | |
|---|---|
| 0 | Reference State |
| 0,ch | Standard Chemical |
| out | Out flow |
| in | Inflow |
| des | Destruction |
| p | Potential |
| ch | Chemical |
| phy | Physical |
| k | Kinetic |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| EFF | Exergy Efficiency Factor |
| FAR | Floor Area Ratio |
| PAR | Plot Area Ratio |
| SEF | Shadow Effect Factor |

# CHAPTER 1

# INTRODUCTION

This chapter introduces the framework of the problem and the aim of the dissertation. A brief structure of the thesis is also presented here.

## 1.1. Problem Definition

In recent years global environmental problems, increasing population, limited nonrenewable energy sources and global climate change have emphasized that the linkage between energy and environment is very strong and relevant. Besides this, the cost of energy from the level of end-users to the multi-national companies is another major problem when the global economic positions of the countries and the companies are taken into account. With these perspectives, there are various attempts to decrease costs and to decrease emissions from an environment point of view. Attempts to decreasing total energy consumption are one of the major discussions besides constructing energy efficient devices and systems. In addition, cheap, sustainable and renewable energy productions are another major study in today's world.

When the global energy consumption for the sectors is investigated it is seen that 51% of total energy production is used in industry, 20% in transportation, and 18 % in residential and 12% in commercial sectors (EIA 2013). Globally 50% of the total energy consumption and 42% of the total water consumption are used in the construction and usage period of the buildings. Furthermore, 50% of the greenhouse gases, 40% of the water pollution and 24% of the air pollution arises from the activities in the built environment (Edwards 2001). It is interesting that 81% of the residential energy demand is used in the heating of buildings (Tokuç 2005). Highlighting this, the numbers above show that the amount of energy used in residential areas cannot be underestimated and any increase in efficiency made in the area contributes to the energy sector and leads to a decrease in the energy cost and emissions. In the literature various studies point out that, buildings densely use energy from various energy sources. Energy used in buildings is mostly for heating, cooling and lighting purposes. This energy is mainly obtained from nonrenewable sources. However, buildings, building blocks and neighborhoods should minimize energy demand while optimizing comfort properties. This can be achieved by considering energy efficiency during the design phase. For example, the use of renewable sources must not be underestimated in the design strategies. Increasing in energy efficiency in the building sector must have a priority in this field of the studies since the built environment is one of the largest energy consumers. These studies can also ease the efforts in decreasing greenhouse gases (CSB 2011).

The reports of "The Organization for Economic Co-operation and Development (OECD)" declare that the OECD average of the ratio of the energy density to the energy per gross national product (which is the indication of the energy efficiency nationwide) is 0.19. Considering that Turkey's value is 0.38, this strongly proves that in Turkey there is a large room for energy efficiency increment in all sectors (Yüksek and Esin 2011).

Taking the increasing energy demand on the increasing population in today's capitalized, industrialized and developed world into consideration, the interaction between energy consumption and building block design is the focus of this study. The relation between the spatial organization of societies and energy systems are complex, dynamic and not identified clearly. On the other hand, differing from the 1980s with its excessive supply of fossil fuels that impacted the world's increased transportation usage and urban sprawl nowadays the environmental aspects have greater importance. This is seen just in considering the global warming and sustainability issues being studied and debated. Historically, the spatial organization of society had been shaped and affected at all levels by nature and the availability of energy sources. When investigating the previous decades, it is seen that energy is only one element in the planning field and energy efficiency was given very little importance in the decision making process of urban planning (Owens 1990).

When the energy efficient planning and design are taken into consideration, basically a relationship of land use and building design (Figure 1.1) comes to the mind (Owens 1990, Ovalı 2009, Mangan and Oral 2013). Energy efficient planning principles systematically investigate the city at three different scales which are the settlement's properties, the building block's properties and the building's properties. Figure 1.2 shows the basics of this framework and the relation of energy and spatial properties. Land use decisions should be made in consideration of how to reduce the effects on climate change, ensuring efficient and effective use of energy and providing sustainable urban policies (Ayan 1985). Moreover, the aim of the energy efficient planning is to help people carry out their daily activities in the most efficient way from an energy point of view, and to minimize the energy usage (Owens 1990).

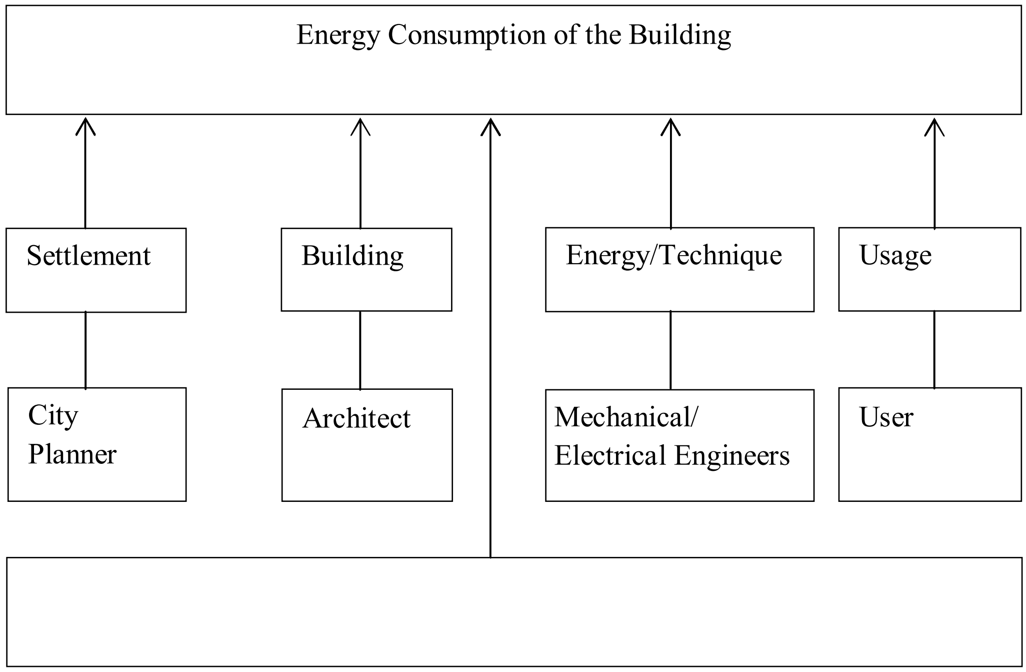



Figure 1.1. Factors and actors affecting the energy usage in the buildings.
(Source: Ovalı 2009, 68)

Nowadays, buildings are usually designed with an abstract and single perspective. This study shows that the context where it will be located and the climate it is built also needs to be considered.

At all levels of land use planning decisions, the use of energy has to be taken into account and, the planners have to develop solutions for efficient use of energy. The land-use patterns directly affect energy consumption and influence the energy systems. This is seen, for example, from the small scale of a house to the large scale of a country. No matter what the scale, however, it is crucial to understand the significance of the energy efficient planning’s contribution to energy conservation.

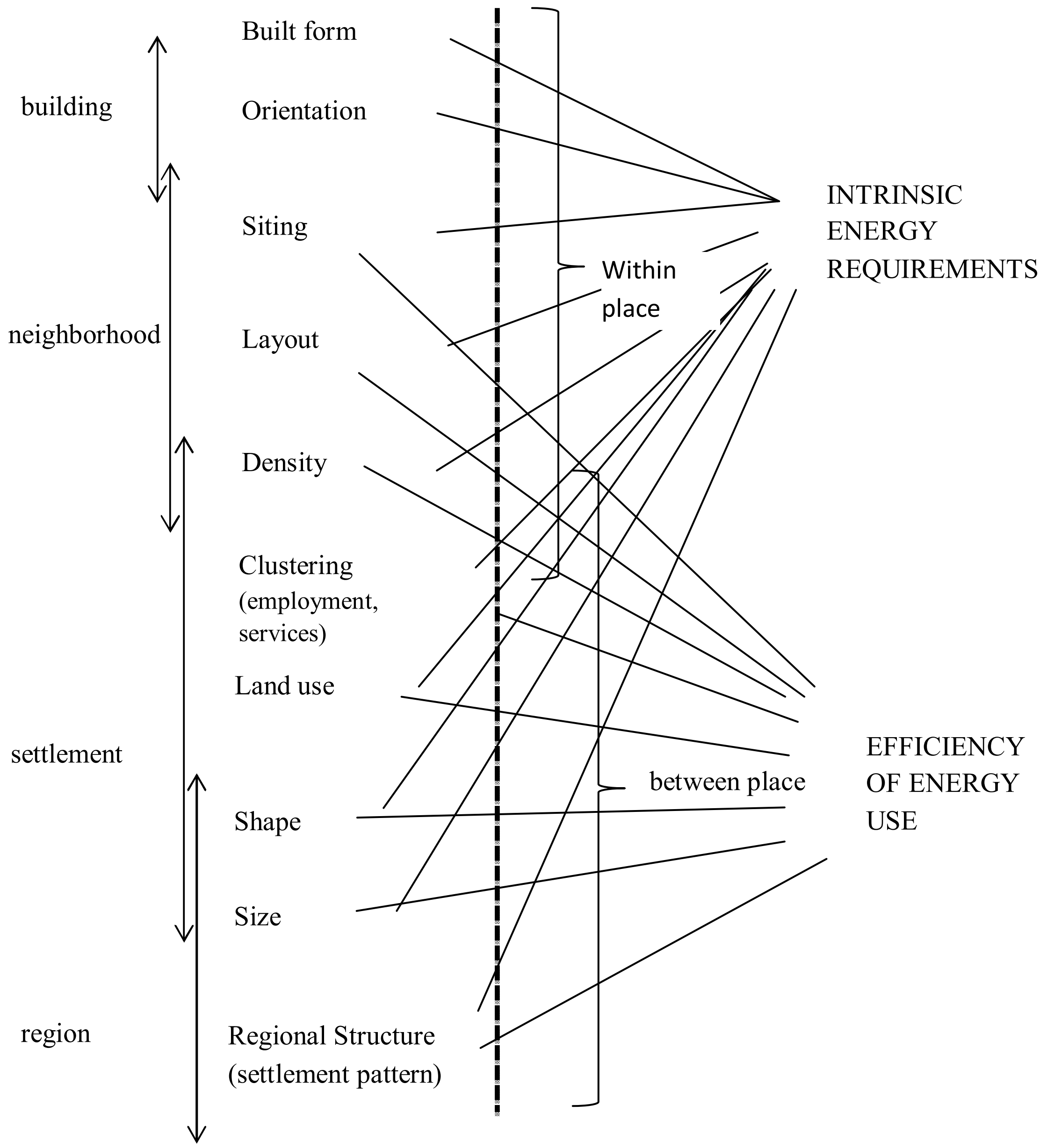



Figure 1.2. Framework for analysis of energy /spatial structure relationship.
(Source: Owens 1990, 60)

When looking from the energy efficiency point of view, the different properties of the spatial structure at different scales are important. The fundamentals exercised when planning and decision making for local energy efficiency planning are as effective for decisions at the regional scale (Figure 1.3). Beside properties like orientation and microclimate at the local scale, wider spatial properties are also important at a regional scale. At small scales, direct forward changes bring considerable improvements. For instance, adjusting the orientation of the building for the sake of energy saving and not adding extra cost to the construction. For comprehensive energy effectiveness on the regional scale, climatic and microclimatic properties of the urban area have to be considered with great care because the loads arising from the small (or house) scale by heating and cooling.

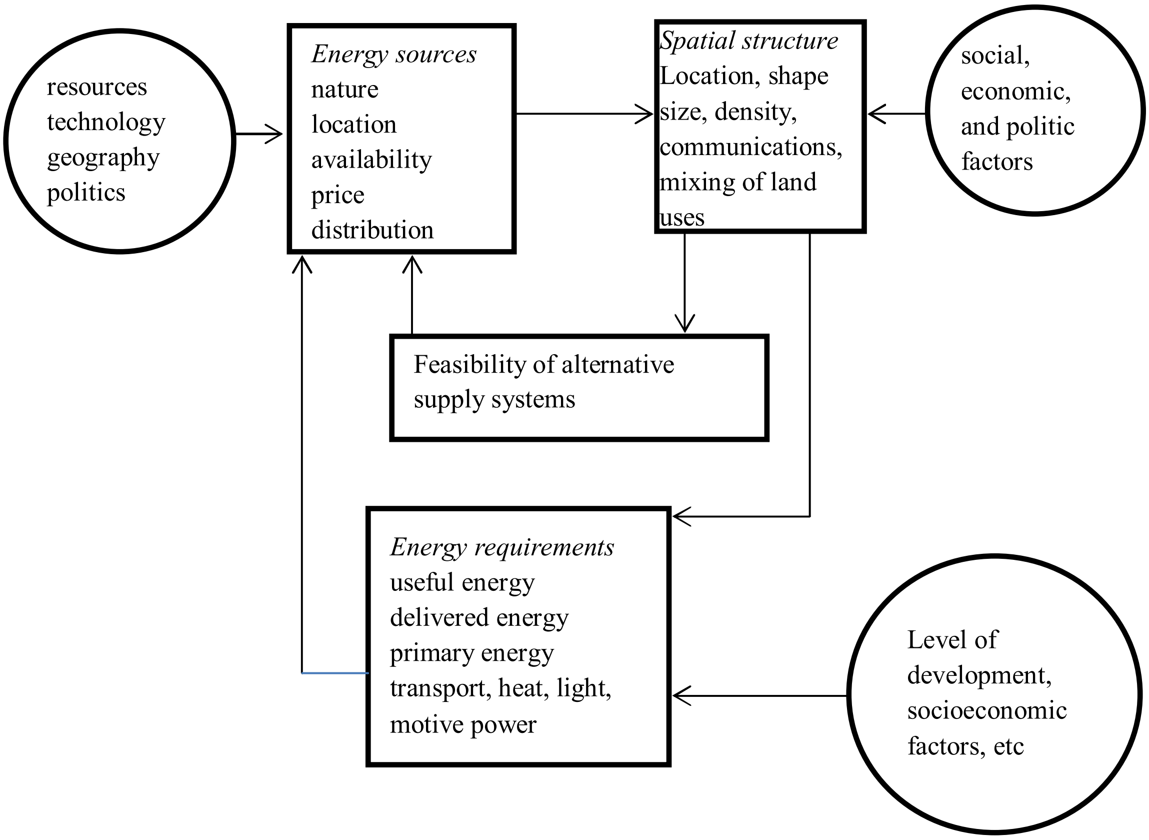



Figure 1.3. The relationship between the energy system and spatial structure.
(Source: Owens 1986, 3)

It is concluded by Ovalı (2009) in her study that 50% of consumed energy in buildings can be conserved when climate friendly building and built environment design is applied. The situation in Turkey, where there is only one Building Act, underestimates the effects of various climate regions in the country. According to the Act 3030 a building is designed and placed 5m from the frontage and 3m from flank front. These standards were taken from German standards during planning of Ankara. However, this plan was for a building in Germany with 2-3 stories, while in Turkey these standards have been implemented that the distance between the buildings increases 0.5 m for every storey in the building (Tokuç 2005). Planning, design and implementation regulations do not take local and regional differences into account. As a result the urban environment is not in a harmony with the local properties. (Aydemir 1989). Similarly, at the building scale, the implementation for the regulation of energy performance in a building only focuses on decreasing the energy demand instead of applying manners of energy efficiency (Çakmanus 2010). The regulation, although, deals with issues like the importance of orientation, passive solar gain, and microclimatic effects.

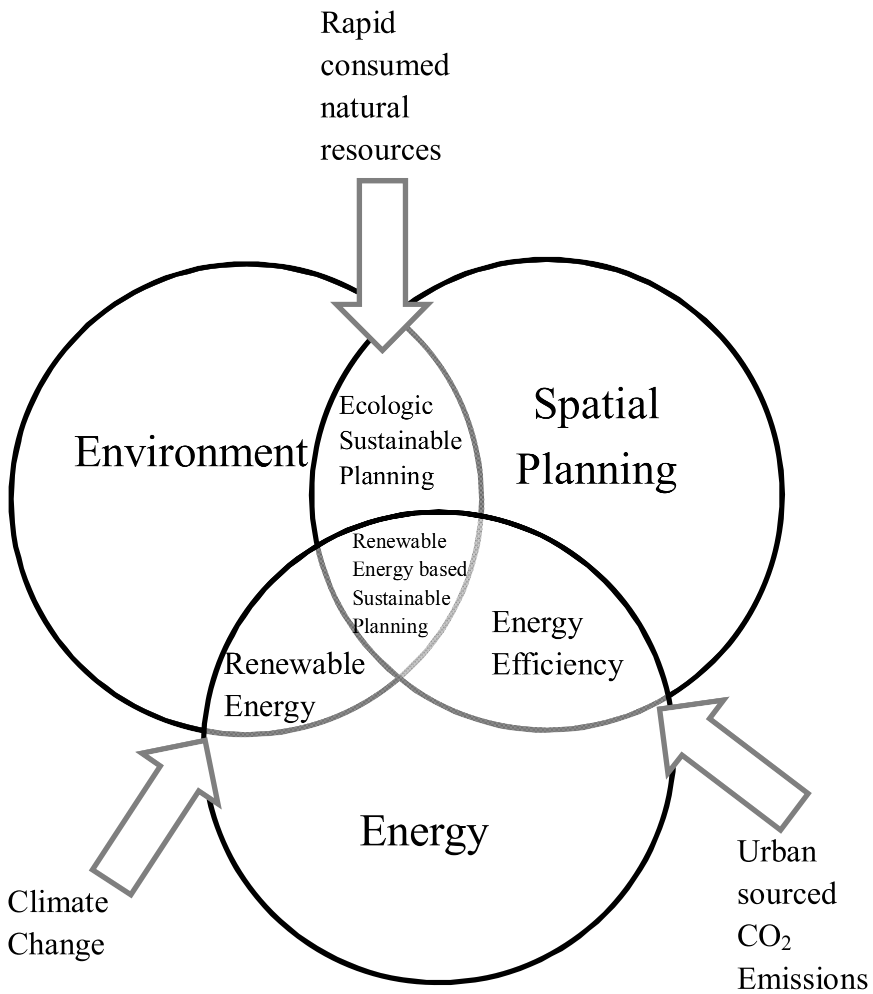



Figure 1.4. The relation between planning, environment and energy.
(Source: Bayındırlık ve İskan Bakanlığı 2009, 766)

In light of the discussion above, this study focuses on the design of an energy efficient building block and underlying the magnitude of energy that can be saved by this from exergy analysis point of view. The scale selected for the study is the building block scale since it is between the building and settlement scales and can provide enough information on the priority of taking energy effectiveness into account in the neighborhood planning and design. In this, it can be noted that the energy is conserved in the area through increasing passive energy input to the area and decreasing the heat loss of it. Moreover, by maximizing the passive energy input in buildings, and by considering the energy effective design parameters in planning and architecture, a more sustainable neighborhood can be formed.

For a sustainable and livable city clean energy must be a priority. For this reason in the design and planning practices, solar architecture must be a leading strategy in along with the local climate properties such as wind.

Preparation of "Act of Sustainable Settlements" is proposed in the report of the Urbanization Council (Kentleşme Şurası) along with preparing long term settlement energy goals (Bayındırlık ve İskan Bakanlığı 2009). Figure 1.4 shows the relation between planning and energy considering environment and shows the solution ways of dealing with this complex problem.

## 1.2.Aim of the Study

This study aims to find out the amount of energy conserved by using exergy analysis in a building block when "energy efficient design" is applied according to the predefined parameters. In other words, it aims to determine the amount of energy-exergy that can be saved for the sake of sustainability using the energy efficient design parameters by exergy analysis. Exergy analysis is defined as a powerful tool for understanding the true characteristics of a system from the perspective of energy by investigating the true potential of its source. This dissertation is a first and unique attempt of introducing exergy analysis into urban planning and urban design literature.

## 1.3.Structure of the Thesis

Chapter one, introduction, presents the problem definition and also aim of the study.

Chapter two reveals the methodology used and states the hypotheses of the dissertation. An investigation of the exergy concept from its fundamentals to the exergy analysis of a building block is also presented here.

Chapter three is the comprehensive literature review that focuses on the studies in the literature. There are three sections focus energy efficient design at building scale, settlement scale and the studies about the energy and exergy analyses.

Chapter four discusses the energy efficient design parameters by a classification of physical environment parameters and design parameters for the built environment.

Chapter five is the case study broken up into five sub-headings. That are, the data for the analysis, information about the case area, details about the proposed design alternatives, the results of the exergy analysis for existing design, and the results of the exergy analysis of proposed design alternatives.

Chapter six is the conclusion and highlights the results found, discusses use of the exergy analysis in the planning literature, and makes recommendations for further research.

# CHAPTER 2

# METHODOLOGY

This chapter informs how this research is conducted in details.

## 2.1.Hypothesis

This study addresses the following two hypotheses (H);

- **H1**: Exergy analysis is a suitable tool for built environment.
- **H2:** Energy efficient design parameters provide energy saving in built environment.

In order to test the hypotheses stated above, the following steps are set;

1. The energy efficient design parameters have been identified through the literature survey,
2. Data gathering for the exergy calculations from the case area Mavişehir, Turkey is carried out (various data from municipalities and institutions, such as plan notes, and meteorological properties as well as metric calculations of the buildings such as the measurements of areas for doors, windows, walls, distances of the buildings, floor areas, roof areas and etc.),
3. The existing state of energy-exergy analysis of selected building block (mass housing) is carried out,
4. The selected building block is re-designed according to energy efficient design parameters,
5. Exergy analyses of the proposed design alternatives is carried out in the building block,
6. A comparison of exergy analysis of existing and proposed design alternatives in the mass housing area is carried out,
7. The amount of decrease in the exergy loss due to energy efficient design is calculated and discussed.

## 2.2. Exergy Analysis

The significance of the energy conservation in all sectors including urban areas is discussed in the previous sections in details. In this chapter, the fundamentals of the exergy analysis are explained and an algorithm about the exergy analysis on an urban area is developed. Exergy analysis is used to analyze the true characteristics of the energy flow in a building block in this study. As being a method that reveals the quality of the energy by including the potential of an energy source considering the environment that it's presently in, exergy analysis brings the investigator the chance to see the true potential of an energy source and energy system. Since the urban areas are one of the most energy consuming sectors any improvement in the energy profile will greatly contribute to the global energy system. On behalf of these applying the exergy analysis on urban systems becomes mandatory for sake of efficient and sustainable settlements.

According to the first law of thermodynamics, energy is conserved not destroyed; it can be converted from one form to another. The first law is interested in the quantity of the energy. However, the second law of thermodynamics bases on quality of the energy. It is interested in production of entropy which is a reduction in qualities, and inability to assess opportunities for doing business. Exergy analysis unites the first and second laws of thermodynamic in a way that the conservation of mass and energy comes from the first law, whereas aiming a decrease in the increase of entropy.

Exergy is maximum energy that can be obtained from a source. Exergy is a quality and the potential of energy that can be transferred to work. The potential work loses when the change of the state defines an exergy loss (Table 2.1). During a state change the decrease in the loss of exergy directly increase the production rates. For this reason, performance of the system can be maximized by minimizing exergy loses. In this context, exergy analysis helps to identify and locate the energy loss points of a system for sake of increasing efficiency and cost reduction as well as decreasing emission. Moreover, the analysis is used in the design, optimization and development of the energy related systems. It can also be said that the efficiency in terms of exergy represents the distance between real performance and ideal performance of a system (Rosen and Dinçer 2001).

Table 2.1 The main differences between energy and exergy.
(Source: Dinçer 2002, 140)

| Energy | Exergy |
|---|---|
| is dependent on the parameters of matter or energy flow only, and independent of the environment parameters. | is dependent both on the parameters of matter or energy flow and on the environment parameters. |
| has values different from zero (equal to $mc^2$ in accordance with Einstein's equation). | is equal to zero (in a dead state by equilibrium with the environment). |
| is guided by the first law of thermodynamics for all the processes. | is guided by the first law of thermodynamics for reversible processes only (in irreversible processes it is destroyed partly or completely). |
| is limited by the second law of thermodynamics for all processes (incl. reversible ones). | is not limited for reversible processes due to the second law of thermodynamics. |
| is motion or ability to produce motion. | is work or ability to produce work. |
| is always conserved in a process, so can neither be destroyed nor produced. | is always conserved in a reversible process, but is always consumed in an irreversible process. |
| is a measure of quantity. | is a measure of quantity and quality due to entropy. |

The importance of the exergy analysis can be summarized in a couple of phrases.

- addresses the impact of energy resource utilization.
- is a powerful tool in design and analysis of energy related systems.
- is a tool for efficient use of energy in energy systems by identifying the points of energy loss in a system.
- is a tool for revealing the possibilities in energy efficiency in a system.
- is an undeniable tool for sustainable development by having these properties (Dinçer 2002).

## 2.2.1. Exergy Analysis Fundamentals

Exergy analysis is a modern thermodynamics method used as an advanced tool for evaluating engineering processes (Figure 2.1). Whereas energy analysis is based on the first law of thermodynamics, the exergy analysis is based on both the first and the second laws of thermodynamics. Both analyses utilize the material balance for a considered system. Analysis and optimization of any physical or chemical process, using energy and exergy, can provide the two different views for the considered process (Dinçer and Rosen 2007).

There are increasing trends in society that relate sustainable development and the efficient usage of renewable energy sources. Sustainable development needs sustainable energy sources. As a tool for increasing efficiency, exergy greatly serves the benefit of sustainability (Dinçer and Rosen 2007).

In addition exergy can provide an opportunity to understand the environmental impacts that cause energy resource utilization. Moreover environmental impact and sustainability of energy systems are also revealed by exergy analysis. Scientists are especially interested in energy systems and their relationship with the environment (Dinçer 2002).

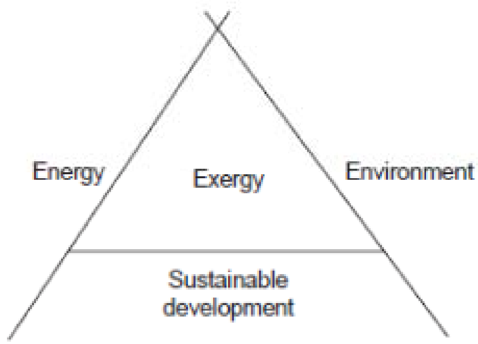



Figure 2.1 Interdisciplinary triangle covered by the field of exergy analysis process.
(Source: Dinçer and Rosen 2007, 37)

Basically, the exergy concept is introduced to overcome limitations of the energy analysis. The exergy expresses the practical value of any substance (or any field matter, e.g., a heat radiation), and is defined as a maximum ability of this substance to perform work relative to its environment (Figure 2.2).

So, exergy is commonly defined as the maximum theoretical work obtainable as the system interacts with its surroundings and comes to equilibrium. Once a system is in equilibrium with its surroundings, it is not possible to use the energy within the system to produce work. At this point, the exergy of the system has been completely destroyed. The state in which the system is in equilibrium with its surroundings is known as the dead state.

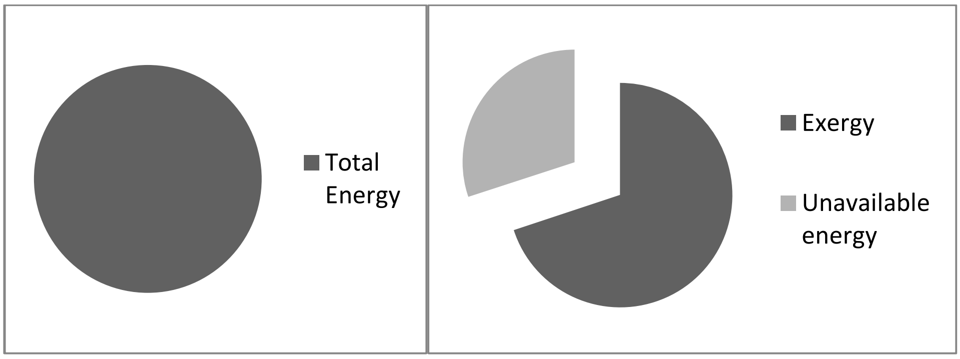



Figure 2.2 Energy, exergy and unavailable energy relation.

Exergy concepts relation to the environment; eases the quantification of economic and ecological problems by underlying the potential of a successful exergy analysis (Mert 2006). While trying to measure the points of lost energy and giving the decision maker of the system a chance to conserve this lost energy, the exergy analysis is also a complimentary tool for ecological conservation. By decreasing the exergy losses and increasing the efficiency, the amount of fossil fuels used in the energy sector decreases. This also results in a decrease in the emission of greenhouse gases. The decrease in energy loss may occur in various sectors such as transportation, industry, residential sectors and others. With such a decrease further investigations could reach national and global levels. The important effects of the relationship between exergy and the environment are seen in the reduction of waste energy emissions, a decrease in resources of energy related sectors and more efficient use of energy (Dinçer 2002).

Moreover exergy is closely related with the sustainable development and can be used for achieving sustainable development (Rosen and Dinçer 2001). As it is discussed previously, exergy analysis reveals the characteristics of an energy related system. It can be a small application or a nation’s energy usage. It helps in identifying a system’s energy effective points or the points of energy loss in the system. Sustainable developments urge us to improve the efficiency through the use of sustainable energy resources. By revealing the characteristics of an energy system, an improvement in the system can be proposed and priorities for decision making processes can be redesigned. Two examples of this are introducing green energy into a system and utilization of related technologies.

Buildings and built environment have energy saving potential. Especially when looking at global effects based on energy, some issues can be solved by the exergy analysis that provides energy efficiency. Energy efficiency can be realized by changing heating and cooling loads and also natural ventilation of both building and building block scales. For sustaining energy sources and conserving the natural environment, energy policies must be integrated into the development of the built environment. Using the concept of exergy can be an effective tool for this aim (Dinçer 2002).

Schmidt (2012) points out that the exergy component of energy is low for heating and cooling of buildings since a comfort temperature is very close to the ambient air. The energy efficiency of a heating system of a building is about 80-90% whereas the exergy efficiency is lower than 8%. However, high quality energy sources such as fossil fuels are commonly used for this demand of energy with low exergy. On the contrary, according to the economic and environmental perspective, high quality energy and exergy should be used in industry. Solar radiation and natural ventilation is important for heating and cooling of buildings. For these reasons, the design of buildings, building blocks and built environment by taking the exergy concept into consideration, is very crucial for revealing the potentials benefits.

A large number of studies concerning the exergy concept have been actualized in various disciplines. For instance from mechanical (Figure 2.3) to chemical engineering, and from environmental engineering to ecological engineering and so on (Dinçer 2002). In the literature review of the study, it is pointed out that there are various studies about the exergy concept on building scale, heating systems in building (Figure 2.4) and total energy consumption of the countries being studied. Nevertheless the exergy concept is not introduced to the city and regional planning field at the scales of urban design and site planning. For this reason, and as mentioned above, this thesis is original in the sense of applying the exergy concept into building block design.

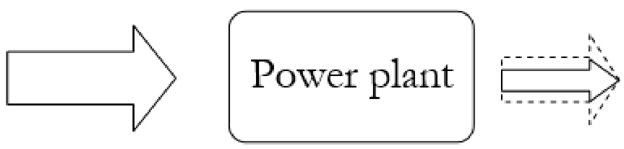



Figure 2.3. Power plant optimization aims at increasing the power output.
(Source: Molinari 2009, 8)

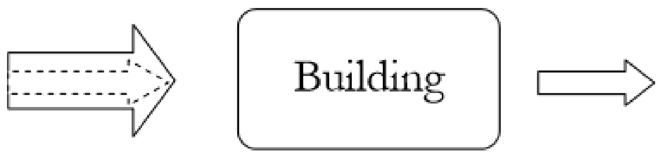



Figure 2.4 Building exergy optimization aims at decreasing the power input.
(Source: Molinari 2009, 8)

As a combination property of a system and its environment exergy depends on the state of both the system and the environment. The unit of the exergy and energy both has similar units as joules.

The physical, kinetic, chemical, potential, nuclear, magnetic, electrical, and surface tension forms are exergy types that may exist in practical applications. Here, the total exergy is assumed to be formed from physical ($Ex_{phy}$), chemical ($Ex_{ch}$), kinetic ($Ex_k$) and potential ($Ex_p$) exergies and used in the calculations accordingly.

$$\dot{E}x = \dot{E}x_k + \dot{E}x_p + \dot{E}x_{phy} + \dot{E}x_{ch} \tag{2.1}$$

The kinetic exergy is the kinetic energy difference of the system with its stationary state so;

$$\dot{E}x_k = \frac{1}{2}\dot{m}V^2 \tag{2.2}$$

The potential exergy of the system can be treated as the potential energy difference of the system with the zero level;

$$\dot{E}x_p = \dot{m}g\ z \tag{2.3}$$

The physical exergy is equal to the maximum amount of work obtainable when the stream of substance is brought from its initial state to the environmental state defined by $P_0$ and $T_0$ by a physical process involving only thermal interaction with the environment;

$$\dot{E}x_{phy} = (U - U_0) + P_0(V - V_0) - T_0(S - S_0) \tag{2.4}$$

$$\dot{E}x_{phy} = (H - H_0) - T_0(S - S_0) \tag{2.5}$$

where, 0 stands for the *reference* environment.

Chemical exergy is the energy resulting from the difference in the composition of a substance with respect to the common components of this substance in the environment. Chemical exergy at P and T can be calculated by bringing the pure component in chemical equilibrium with the environment. For pure reference components, the chemical exergy consists of the energy that can be obtained by diffusing the components to their reference concentration pressure.

$$\dot{E}x_{ch} = RT_0 \ln\left(\frac{P}{P_0}\right) \tag{2.6}$$

The chemical exergy of substances, with respect to their reference environment is calculated by;

$$\dot{E}x_{ch} = \Delta G - \sum_j v_j \dot{E}x_{0,ch,j} \tag{2.7}$$

where ΔG denotes the change in the Gibbs energy of formation, ν denotes the stoichiometric coefficient and $Ex_{0,ch,j}$ denotes the standard chemical exergy of the substance.

Exergy efficiency (so-called second-law efficiency) of a process or a system can be defined as the ratio of the exergy recovered (exergy output) to the exergy input (Mert 2006).

$$\eta = \frac{\dot{E}x_{out}}{\dot{E}x_{in}} \tag{2.8}$$

*or;*

$$\eta = 1 - \frac{\dot{E}x_{des}}{\dot{E}x_{in}} \tag{2.9}$$

Exergy output is sometimes called the desired exergy output of useful exergy output (Mert 2006).

### 2.2.2. Exergy Analysis of a Building Block

Calculations for the exergy load of residential building blocks are complicated. This process starts with the data-handling which is composed of some major design parameters of buildings and building blocks which are listed below and explained in Chapter 4:

- Building Scale
  - Location of the building
  - Orientation of the building
  - Building form
  - Area/volume ratio of building
  - Openings to building ratio
  - Size of the building
  - Design of the building
  - Insulation of the building
  - Resident information
  - Heating and cooling system properties
- Building Block Scale
  - Building block form
  - Size of building block
  - Perimeter to area ratio
  - Landscaping and planting of building block
  - Microclimatic properties (wind, average temperature, so on)
  - Shadowing due to the configuration of buildings
  - Topography of building block

After completing processing and analyzing data, exergy calculations take place:

- Calculation of the Shadow Effect Factor (SEF)
- Calculation of the exergy load of each building for heating and cooling
- Calculation of the exergy loads for the building blocks

The aim of the calculation procedure is to calculate the $\dot{E}x_{demand}$ values which show us the exergy need of the building that is calculated using the assumptions given above. For the calculation of exergy demand, the procedure proposed by LowEx (LowEx, 2012) (Appendix B) is utilized.

$$\dot{E}x_{demand} = \dot{E}x_{loss} - \dot{E}x_{gain} \tag{2.10}$$

$\dot{E}x_{loss}$ is calculated by the transmission losses through the doors, walls, windows and roofs.

$$\dot{E}x_{loss} = \dot{E}x_{loss,transmisson} + \dot{E}x_{loss,ventillation} \tag{2.11}$$

$$\dot{E}x_{loss,transmisson} = \sum U_i.A_i.(T_i - T_o) \tag{2.12}$$

Exergy loss by transmission is calculated by considering the heat transfer coefficient of walls, doors, roofs and ceilings ($U_i$) as well as the areas ($A_i$) and the indoor ($T_i$) and exterior ($T_o$) air temperature difference.

$$\dot{E}x_{loss,ventillation} = C_p \rho.V.n_d.(1-n_v).(T_i - T_o) \tag{2.13}$$

where $\rho$ and $C_p$ is the density [kg/m$^3$] and specific heat [kj/kgK] of air respectively. $n_d$ and $n_v$ are the air exchange rate [m$^3$/h] and the efficiency constants, respectively. V is volume [m$^3$].

$\dot{E}x_{gain}$ is a result of solar heat gains through windows which is a function of SEF. Other gains, such as lighting (2 W/m$^2$), that are arising from the auxiliary equipment in the houses are also taken into consideration.

$$\dot{E}x_{gain} = \dot{E}x_{gain,solar} + \dot{E}x_{gain,\text{int}ernal} \tag{2.14}$$

$$\dot{E}x_{gain,solar} = I_s.\left(\frac{100 - SEF}{100}\right).\left(1 - F_f\right).A_w\, g \tag{2.15}$$

$I_s$ is the solar radiation [W/m$^2$], $F_f$ is the window frame fraction taken as 0.3, $A_w$ is the window area [m$^2$] and $g$ is the total transmittance.

$$SEF = \left( \frac{t_{shadow}}{t_{daytime}} 100 \right) \quad (2.16)$$

The Shadow Effect Factor (SEF) is an indication of a building's blockage by the shadow of another building. This is the effect of the overlapping shadow on the building standing behind another.

SEF is calculated by determining the ratio of the shadowed time ($t_{shadow}$, [min]) of the building to the daytime ($t_{daytime}$, [min]) with direct sun light access in an approximate manner by using the 3D model of the area.

$$\dot{E}x_{gain,internal} = n_o . \phi_{i,o} + A_N . \phi_{i,e} \quad (2.17)$$

where $n_o$ is the number of occupants, $A_N$ is the floor area of the building [m$^2$], $\Phi_{I,o}$ and $\Phi_{I,e}$ are specific internal gains of occupants [W/occupant] and specific internal gains of equipment [W/m²], respectively.

$\dot{E}x_{input}$ is calculated depending on the $\dot{E}x_{demand}$ by considering the efficiency of the heat production and heat distribution systems, which are used as 0.95 and 0.93,respectively.

The exergy flexibility factor is calculated by 2.18. This is an indication of the possibility of replacing a given system by another to meet the exergy demand (Hepbaşlı 2012).

$$EFF = \frac{\dot{E}x_{demand}}{\dot{E}x_{input}} \quad (2.18)$$

In order to reach the aim of the study, first exergy analysis method of the existing building block has been applied by gathering various data from municipalities and institutions, such as plan notes, and meteorological properties. Second, energy efficient design alternatives are developed for the same area considering the parameters gathered from the literature. Finally, the exergy analysis method is applied to the proposed design alternatives of the case area in order to understand the effect of the energy efficient design on the energy usage of the building block in terms of exergy.

# CHAPTER 3

# ENERGY EFFICIENCY

The studies investigated in the literature concentrate on energy saving and conservation. It is found that generally there are three main topics investigated in the literature. First, energy efficient design parameters, second, analysis of measuring energy efficiency (energy analysis and exergy analysis), and finally integrating renewable energy sources (passive and active system.) The literature reviewed in this chapter is summarized in (Figure 3.1).

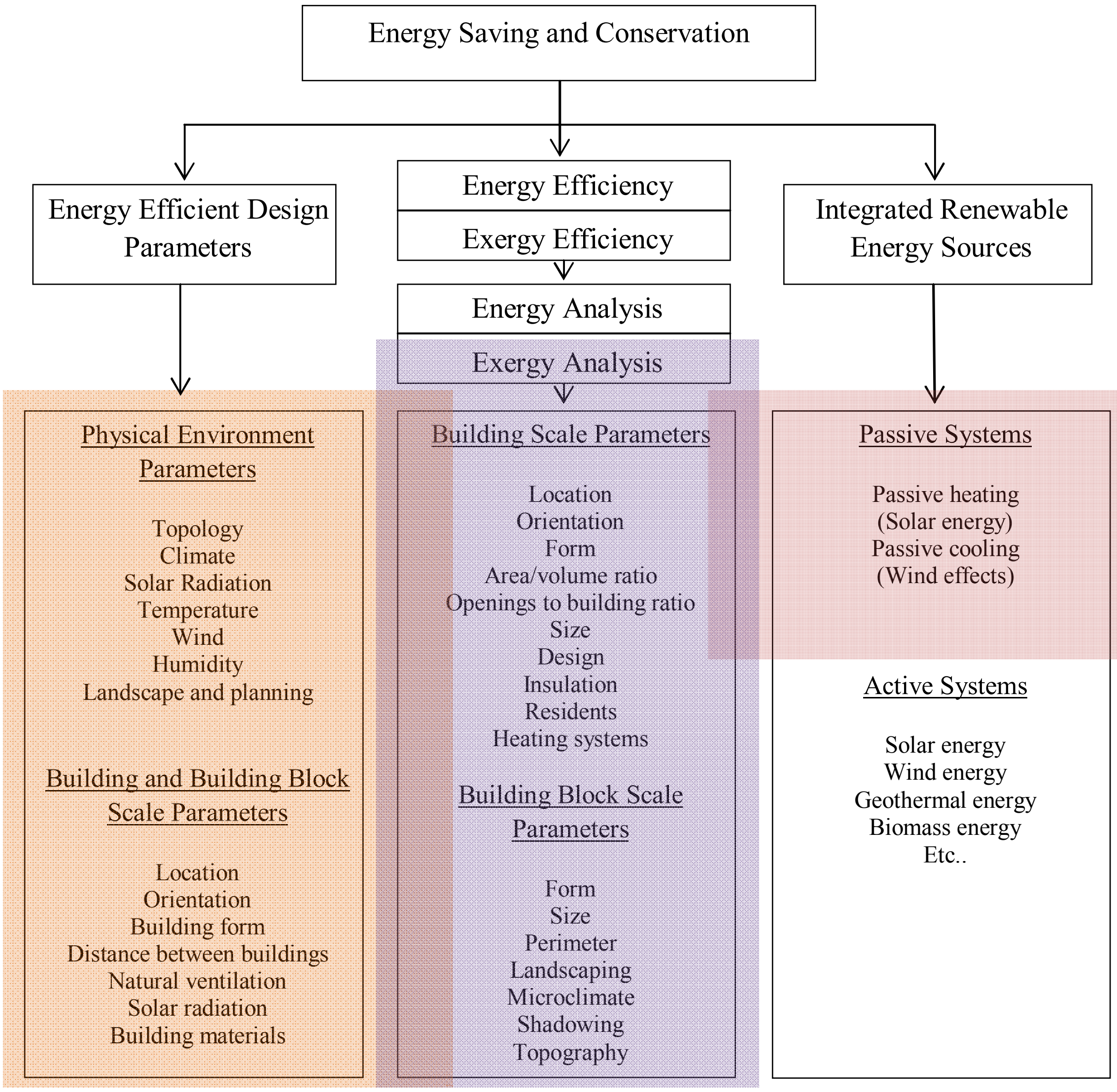



Figure 3.1 Structure of the literature.

## 3.1. Energy Efficiency Based on Building Scale

Several studies are investigated about energy efficient design considering aims, cases, design parameters, climate region and findings.

Aksoy (2002) aims to deduce what level of influence passive design parameters - like the shape factor of a building, physical properties of buildings (i.e. envelope and insulation thickness), transparency ratio and orientation of building - have on annual heating energy consumption. The climate is assumed as mild-dry in his this study. For that purpose, rectangular or square masses with three different shape factors of building without any indents or protrusions are designed. Masses, each with 121 $m^2$ floor area, are then analyzed in 9 different orientation angles with 10 degree shifts between them. The findings of these analyses agreed with the existing literature. In terms of the shape factor of buildings, those with south and southwest facades have more advantages than the buildings with north and northeast facades in heating energy efficiency. In terms of form, 1/1 (length/width) shape factor is the most efficient in heating energy efficiency. The insulation thickness of building and heating energy required is inversely proportional. As the insulation thickness increases, the energy amount required for heating decreases (Aksoy 2002).

Ratti et al. (2003) investigate the relation between the form of the buildings and environment. Innovative techniques are used for environmental urban analysis. These are based on image processing and an integrated approach to looking into the complexity of environmental behavior of the urban context. Their case study is applied in hot-arid climatic context. The investigated parameters consist of surface to volume ratio, sky view factor, shadow density and daylight distribution. It is found that when certain factors are combined together, a decrease in environmental impact and energy efficiency take place. Examples of this are larger surface area and high thermal mass, daylight via the courtyard and shallow plan form, narrow spaces for shade and improved thermal comfort despite increased heat island is better for the sake of decreased environmental impact and energy efficiency (Ratti et al. 2003).

Işık (2007) aims to display, the effects of energy consumption of the buildings which have high energy exhaustion and also advance proposals to improve energy activity in existing buildings in Turkey. The parameters that is effective for energy efficiency is investigated under headings of heat loss, fuel source, solar energy, orientation and building form. The energy effective design parameters and the retrofitting parameters for new and existing buildings are discussed in this study. As a result, it emphasizes that buildings must have an energy efficient design and that the regulations must support it (Işık 2007).

In the study of Çalışkan (2007) basic ecological design parameters are introduced and related example designs are created. Two five-storey buildings are located in the selected urban area in a triangular pitch formation. A compact design is developed while having the necessary space in a rectangular shape. Special care is taken to place them in such a way that buildings do not prevent solar radiation and scenery for each other and their southern fronts receive equal amounts of sunlight. Each housing unit is designed for a family of 3-4, with a 90 $m^2$ floor area and with simple geometry. The buildings are placed having an orientation of 30° from south to east. The aim is to use passive and active methods in harmony together in order to preserve energy, water, and natural habitat (Çalışkan 2007).

Soysal (2008) evaluates the various approaches to increase energy efficiency in residential buildings and tries to deduce in what scale these approaches are conveyed in the design phase. Sosyal's findings are consistent with other researchers both in building scale and building block scale; the findings are supportive of the literature. The case area consists of five blocks of 14 five-storey buildings in Ankara Turkey. The study emphasizes that the location and the orientation of the buildings must be taken into account in the early stages of the design. The locations of the groups of building and the relations between them, as well as their relationship to other nearby existing buildings must not be underestimated. In the field search it is seen that since these relations are neglected, many of the buildings are greatly affected from the shadow of the other buildings. This is especially true for the buildings that face south with an all-day shadow effect (Soysal 2008).

Baruti (2009) investigates energy efficient building technologies in order to optimize design parameters for climate-based indoor air temperature standards. Parametric models were generated and used to investigate the influence of various design parameters in terms of the indoor thermal comfort and energy demand. The investigated parameters are; orientation influence, use of shading devices, insulation, building services, various wall constructions and thermal mass. The analysis is carried out in hot climate. The results of the study shows that shading is very important in hot climates as well as use of granite in construction with reduced window size (25%) and use of double glazed glass (Baruti 2009).

Serin (2011) inspects the renewable resource potential of Izmir and suggests a nature-friendly and applicable ecological housing model that reduces energy requirements to a minimum and uses renewable energy resources efficiently. Each district of the city is analyzed in terms of renewable energy sources and Serin evaluated the given scores. As a result, the district of Seferihisar is determined as the most favorable in terms of renewable energy resources. By analysis of climate, sun and dominant winds, a model is proposed that makes the most use of solar energy, down to the details of design and material choices. Nine apartment blocks with two-storey buildings are designed with linear form with an east-west orientation. Each building is then constructed with a southward orientation to maximize the solar gain. Moreover, sufficient distances are presented between buildings to utilize solar gain and wind flow. The suggested model is tested by “Heat Isolation Calculation Program of the Chamber of Mechanical Engineering” and is confirmed as “Type A building” (Serin 2011).

Abed (2012) evaluates the effect of the building’ form on thermal performance in residential buildings. In addition to the building form, the climate’s impact on energy performance is also calculated. Some computer programs like Ecotect and IES are used in this study. The research investigates the thermal performance of different geometrical shapes and orientations of the housing unit and within different urban configurations. It is found that up to 39% of total energy usage can be conserved with the selection of the proper form. This is length ratio (W/L) as 0.8 , (roof/ walls) ratio between 0.4 to 0.6, L and U shape as the form, spacing ratio (L1/L2) as 0.1 and aspect ratio (H/W) as 0.5 (Abed 2012).

Attia (2012) claims a tool for developing Net Zero Energy Buildings (NZEB). A simulation aid based method ZEBO (Zero Energy Building Optimizer) is developed. A hot climate case done in (Egypt) is selected for the investigation. First passive and low energy cooling strategies are presented in the study as well as introducing renewable choices with respect to local conditions. Attia stated that the influence of the use of aiding tools improved the energy performance up to 64.1% which are calculated in three workshops (Attia 2012).

These studies reveal that a building’s energy performance can be improved up to 60% by using the parameters in a proper manner such as construction materials and localization.

## 3.2. Energy Efficiency on Building Block Scale

In the project of Ok (1988), a quantitative method is developed for optimization of parameters of design in the settlement scale. In a building's formation, building form parameters are determined by an element of solar radiation and wind effects in a selected settlement area. The optimum design parameters are applied to an area located in Istanbul (Turkey) which belongs to a mild-humid climate region. It is found out that when the settlement density increases the solar radiation that reaches to the vertical sides of the buildings decreases. The buildings that have 1:1 form factor have a minimum solar gain while buildings that have 1:1.38 form factor have maximum solar gain. In this study 16 different analyses, each having 22.5 degrees of difference, have been applied in between the period of 21 January and 21 July. It is also concluded that the spacing between the buildings are positively effective on the amount of solar gain because of the decrement of shadow formation on the buildings (Ok 1988).

In the study of Shashua-Bar et al. (2004) a quantitative analysis has been studied in order to investigate thermal impact of proposed building arrangements on the urban canopy layer, air temperature. This was conducted in the summer in a hot-humid region. It is proved that the wider the distance between two buildings in an urban environment the lower the temperature increment is seen. With respect to the building width, there can be up to 2 K of temperature increment when the distance between the buildings is decreased to a ratio of 0.67. On the other, hand they have concluded that the orientation of the streets and buildings has negligible effect on the temperature increment in the streets from a solar energy point of view. This is without considering the indoor solar energy gain (Shashua-Bar et al 2004).

Tokuç (2005) evaluates the need to solve the problems identified in literature and occupant's surveys, by using energy efficient architecture and technology. Energy efficient building parameters are categorized with headings of "settlement scale", "volumetric scale", "spatial scale" and "building element design". These parameters are analyzed in detail in Mavişehir-1 mass housing and Karşıyaka apartment blocks, both located in Izmir, Turkey. Occupants' surveys are obtained afterwards. It is determined that solar factor is ignored in orientation of spatial organization in design. The thesis also deduces the recognition and consideration of potential problems that could take place during occupation period of the design stage proactively which would reduce the damage to structures' aesthetical value (Tokuç 2005).

Ratti et al. (2005) investigate the relation between the urban grain and the energy consumption in three cities London, Toulouse and Berlin. The investigated parameters are urban geometry, building design, the auxiliary equipment efficiencies and internal consumptions of the occupants. It is concluded that the effect of passive to non-passive zones are as important as the effect of the surface to volume ratio in buildings. 10% of energy consumption is proposed by applying proper urban geometry in the urban design (Ratti et al. 2005).

Ercoskun (2007) aims to present an approach for the future sustainable city. SWOT analysis is carried out and the ecological footprint of the case area is calculated. An eco-tech design guide is prepared and implemented for mild-dry climate region. As a result of the study, it is seen that a 0.2% ecological foot print decrement occurs in energy effective buildings. The calculation method given in the study also showed a 0.001% decrement in the ecological foot print depending on if transportation systems keep asphalt to a minimum and increasing the green roads. More important than these, a 40-60% decrement in energy based footprints can be achieved by retrofitting infrastructures such as waste water systems and waste to energy transformations in the buildings (Ercoskun 2007).

Karaca (2008) analyzes the energy efficiency methods adopted by the "Republic of Turkey Prime Ministry Housing Development Administration of Turkey" (TOKI) in their projects. For that purpose, around 7% of all buildings built by TOKI between 2003 and 2008 are chosen. Sample subjects are chosen considering their project types and climate region. These 7% samples are separated into two groups by their production period (between 2003-2006 and between 2007-2008), keeping in mind the seven different climate regions and housing types as well. The difference from an energy point of view are tried to be identified between, the energy efficient design strategies in different climate regions and in various housing types. The results show the lack of attention to energy efficient design strategies and that mass housing projects are not created by taking climate factors and the general properties of settlement into consideration (Karaca 2008).

Canan (2008) aims to provide solar control -by means of the "solar envelope" method - to relate urban and architectural design scale in mass housing areas. The study tries to prove that the laws of construction are not effective as it is desired from an energy point of view with the defined parameters of density, spacing, height and the buildings number of storey. If these parameters are related to each other well, maximum solar effect can be gained. The analyses are carried out on the subject that "buildings prevent the solar radiation of other buildings" in an existing mass housing area. Various alternatives of legislations are developed and the results are compared. The main parameters of the comparisons are number of stories and the construction density. With the developed alternatives, the use of complimentary design approach is tested. It is seen that with the complimentary design approach, number of stories, density and formational specialties various arrangements can be made for a defined area. It is concluded that the maximum construction area can be achieved by using the solar envelope method. For increased solar gain and energy effectiveness the building design and urban design must be united and considered together. It is also seen that the existing structures did not take the solar gain factor into account in their design phase. In order to overcome these problems the necessity of writing up a new construction law is proposed (Canan 2008).

Ovalı (2009) examines the ecological design parameters of the climate regions of Turkey in order to increase the conservation of energy and solar energy gain in buildings. In order to increase energy efficiency, the importance of the physical environmental factors and the built environment of different climate regions are emphasized. The design parameters (Table 3.1) that need special focus are identified. In this perspective, Kayaköy (Fethiye-Muğla) compound, which is located within the "hot-humid" climate region, is analyzed and is found to be in accordance with the ecological design parameters for energy conservation. To increase the energy gain even more, active and combined methods are advised (Ovalı 2009).

Hisarlıgil (2009) argues about the effect of climate properties on residential energy performances in relation to building block's properties. He aims to identify the energy efficiency principles in the building block scale and in perspective of climate and energy relationship. Hypothetic building blocks are designed in mild-dry climate region. In this study energy efficient design depending on climate factors are discussed on several scales such as building, building block and settlement. Building blocks have the form of 6m*12m and 12*12. Buildings are designed and analyzed in 2, 4, 8 and 12 storey test models. The difference between the heating and cooling loads is higher in low-rise and high-rise buildings (two and twelve storey buildings) but smaller in mid-rise buildings such as the four and eight-storey ones. In the study it is seen that the spacing between the buildings is 36meters in parallel and must be twice the height. In addition, optimum building block is calculated as 2 hectare for minimum transportation and usage in which building forms must be 1:2. Considering these effects it is concluded that four-storey buildings are optimum when the heating and cooling loads and other effects such as solar gain and wind are taken into account. Also it is said that the transportation corridors must be designed in a way that will allow wind to pass in the summer for increased cooling and to block the wind in winter (Hisarlıgil 2009).

Barreiro et al. (2009) examine strategies about increasing energy efficiency in urban design and planning. The study evaluates a new methodology that integrates concepts of energy efficiency in the overall planning and design process. The case area selected is in Toledo, Spain. The methodology evaluates energy efficiency solutions at different scales and stages within the planning and construction process of both building block and buildings. Several parameters are taken into account such as construction materials, orientation, housing density and building typology. Also the proposed integrated methodology attempts to be improved and adapted to a wide-reaching design for energy efficient urban communities (Barreiro et al. 2009)

It is seen that there are various approaches when conducting an analysis in scales larger than a building. Most of them investigate the forms of the buildings and building block scheme for the sake of increasing solar gain. Besides the parameters arising from various climate factors, occupants are also discussed and analyzed from an energy efficiency and conservation perspective.

## 3.3.Energy and Exergy Efficiency

In this section the studies about energy and exergy efficiency predominantly on buildings are introduced. By means of these analyses and studies, the energy efficiencies of the buildings and larger scales are attempted to be calculated.

Schmidt (2012) optimizes the exergy flows of buildings for identifying the potential increase on energy efficiency. The low exergy (LowEx) approach is utilized in this study and the difference between energy and exergy analyses are shown for an existing building and a LowEx building is formed (Schmidt 2012). It is shown that exergy is considerably destroyed in a building system starting from fuel processing and through the distribution.

Koroneos and Kalemakis investigate the exergy indicators that are the ratio of the renewables and low temperature heat networks in the exergy of the system for a built environment. The study covers the application of the exergy analysis to the building sector and the introduction of suitable exergy indicators. These indicators are used for providing reliability over time, information to policy makers and awareness of potential environmental problems arising from human activities. As a result of this study, investigation of a hypothetical case involving the application of renewable energy sources, a 10-50% of the overall exergy need is determined (Koroneos and Kalemakis 2012).

The study of Meggers and Lejbundgut covers utilization of exergy and anergy concepts for performance increment in buildings and they have proposed a new perspective for buildings. In order to achieve this, better reference environment classification has been completed. Furthermore, clarification for the use of the ambient environmental conditions as reference environment for exergy analysis of whole buildings have been developed (Meggers and Lejbundgut 2012).

Balta et al. have developed an energy option for buildings in a sustainable manner. A building is selected as a case in this study and several options for heating are implemented in the study such as electric boiler, cogeneration, biomass/wood, ground heat pump water–water heat pump borehole/glycol, standard boiler and solar collector. Energy and exergy analysis of all these options are carried out and as a result the exergy efficiency values are calculated as 2.8%, 5.5%, 6.0%, 6.4%, 6.1%, 5.4% and 25.3%, respectively (Balta et al. 2011).

In the study of Depecker et al. a relation between heating consumption and shape is searched. A parameter to characterize the shape of the buildings is introduced as shape coefficient. This is the ratio between the external skin surfaces and the inner volume of the building. Fourteen buildings have been investigated in this study and it is shown that the energy consumption is inversely proportional to the compactness (weak shape coefficient) in sunny winters, but it is not the case in mild climates (Depecker et al. 2001). Depending on the proper shape factor choice, it is found that up to 30% of consumed energy can be conserved.

Another study (Barrerio et al. 2009) investigates the energy efficiency of an area and proposes an integrated energy supply methodology that examines the relationship between planning and efficiency. They proposed a revision on the planning and building protocols for the optimization of the community's energy efficiency strategy and also proposed an integrated methodology to improve and adapt the design for energy efficient urban communities.

A review on analyzing the energy utilization and efficiency of countries has been carried out by Utlu and Hepbaşlı. In their study, a classification of studies was conducted and the approaches applied were then investigated in terms of subsectors, such as utility, industrial, residential–commercial, and transportation sectors. The aim was to give attention to the degree of effective and efficient use of natural resources by country (Utlu and Hepbaşlı 2007).

In a different study Utlu and Hepbaşlı conduct a study on the energy and exergy analysis of the Turkish residential–commercial sector for the years of 2000 and 2020. Total energy and exergy inputs, annual fuel consumptions in space heating, water heating and cooking activities as well as electrical energy uses by appliances, are taken as parameters in the study to discover the energy efficiency and the exergy efficiency. As a result, Turkey's overall energy and exergy utilization efficiencies are found as 44.91% and 24.78% in 2000, and 55.15% and 30.44% in 2020, respectively (Utlu and Hepbaşlı 2005).

Ozturk et al. investigate an estimation study on the residential exergy input and output by using a genetic algorithm. A model is developed including the parameters of gross domestic product, population, import, export, house construction, cement production and basic house appliances consumption. This is then applied to the Turkish residential sector. It is found out that their developed model is handy for predicting the residential–commercial exergy input/output values of Turkey (Ozturk et al. 2004).

An extended exergy based urban ecosystem analysis is carried out by Liu et al. The composition of extraction (Ex), conversion (Co), agriculture (Ag), industry (In), transportation (Tr), tertiary (Te) and households (Do) sectors for Beijing are taken into account in the study. It is shown that energy and resources must be consumed to maintain the structure and function of a city. They concluded an exergy-based network analysis can be used as an integrative tool for evaluation, policymaking and regulation for ecosystem management (Liu et al. 2010).

The exergy analysis for evaluating the sustainability of an urban area is conducted by Balocco et al. The impact of the building's emissions has been evaluated and energy and exergy efficiencies of the buildings are calculated. They concluded that the technological alternatives, strategies and designs that produce lower environmental impacts can be achieved by an exergy analyses (Balocco et. al 2004).

Akyol (2006) aims to measure the energy consumption by making improvements in the facades of the buildings. In this study, energy and exergy analysis was conducted on two same types of residential buildings. Located on the campus of Ataturk University, Block-29 and Block-30 have the same heating energy consumption of 330 kWh/m2 per year. In the beginning the external walls of both blocks had no insulation. In Block-30, top quality external insulation was placed, as well as other important energy savings measures were carried out. The effects of these implementations were observed using Block-29 as the reference building. The effects implemented to Block-30 were determined by comparing with the reference building. The measurements of heat consumption and temperature carried out in these buildings during the 2004-2005 heating season were used as comparison parameters. On the result of measurements, it was determined that Block-30 consumed 51.3% lower thermal energy and due to its external wall insulation, the heat losses through walls decreased 81% in proportion to Block-29. With the total energy amount Block-30 consumed during the measurement period of 165 days, Block-29 could be heated for only 57 days. Exergy loses through the external walls were also calculated in this study and it was seen that in equal heat consumptions, exergy losses through external walls of Block-30 was 94% lower than Block-29 (Akyol 2006).

Regional and global exergy and energy efficiency are roughly estimated in the study of Nakicenovic et al. (1996) for an urban area. The investigation starts from energy sources and their exergy values to the useful exergy used in the urban area. All the conversion and transformation systems about the exergy are taken into account. It is found that the exergy and energy efficiency in the world is 10% and 30% respectively. It is indicated that energy efficiency can be improved up to 10 times the present value.

## 3.4.Summary and Evaluation

Previous studies have documented that two different scales are investigated in the literature for perspectives in energy efficiency: building and building block. A considerable amount of literature based on case studies has been published for investigating energy efficient design parameters and given in Table A.1. Numerous studies have also focused on “physical environment design parameters” and “building design parameters.” However, there has been relatively little literature published on the use of renewable energy, such as energy production, and conservation, based on renewable energy sources.

Much research on exergy focuses on building scale while a great portion of the literature has not utilized all of the parameters that are effective in energy performance, effectiveness and efficiency in the settlement areas.

The studies that only take the building parameters into account did not take the relation of the buildings with each other and surrounding environment into account. Only a limited number of studies (Canan 2008, Karaca 2008, Soysal 2008, Ovalı 2009, Barreiro et al. 2009) evaluated the energy performance with using the some of the parameters and they only conducted a quantitative research.

Besides this, the studies on exergy related topics only focus on building scale, rather than the neighborhood or settlement scale, that deal with the properties of the buildings and construction materials.

Most of the literature efforts did not take the use of renewable energy sources into account and none of them considered local renewable energy resources (solar radiation, wind energy, geothermal, wind, and biomass) which must be determined and integrated in the planning policies.

This dissertation contributes to the literature by integrating exergy analysis into planning and urban design (building block) and taking into account most of the parameters that are effective in the energy performance of the settlement area. While most of the previous studies focus on engineering concerns at building scale, this study is the first in using exergy analysis at the building block scale in the urban planning field. It is applicable since most of the parameters of exergy analysis overlap with parameters of energy efficient design.

In this study, besides the construction materials, orientation and location properties, solar radiation and wind effects are also taken into account in the exergy analysis. Though various renewable sources can also be used for supplying energy to the area, this is not covered by this study.

To sum up, the significance of this dissertation is more clearly seen from several ways;

•Exergy analysis is useful analysis technique that can be used in the urban planning field. Till now, exergy analysis is only used in building scale in the literature.

•Energy efficient design parameters are used in the building block scale in a comprehensive manner.

# CHAPTER 4

# ENERGY EFFICIENT DESIGN PARAMETERS

Parameters and factors rely on the site and building design and are important from the points of view energy conservation and climatic comfort. These effects can be investigated under two groups: physical environment parameters, and design and construction parameters. Investigated physical design parameters are topography, climate, solar radiation, temperature, humidity, and wind. Investigated design parameters are; layout effects on the built-up area, orientation, location, building form, distance between buildings, building envelope and insulation, and natural ventilation.

## 4.1. Physical Environment Parameters

Factors of the physical environment commonly influence the size, shape and various properties of the buildings in the built environment. Thus properties like location, topography, prevailing wind direction and magnitude, outdoor temperature, humidity, soil properties, ground safety status, water sources of surface and ground, landscaping, wildlife habitat effect directly the design considerations and constraints in the built environment (Ovalı 2009). These parameters also directly effect the energy consumption and conservation properties of the buildings. For this reason, these factors must be combined in a comprehensive way in order to obtain an energy sensitive and energy efficient design.

### 4.1.1. Topography

A settlement pattern that is compatible with the natural structure of the land and environment is crucial when considering energy effectiveness, sustainability and protection of the environment. In this concept the detailed investigation of the land and topography is very important for sustaining a consistent design.

The topographical location of the building and the urban area directly affects the solar gain of the area and natural climate effect. The inclination of the area influences how the solar radiations angle strikes the ground.

Generally, slopes up to 20% can be classified as lands that can be suitable for settlements. The areas with slope values between 20 to 40 % can be used for settlements only with special construction properties. Areas with larger slope values than 40% are not generally suitable for development and settlements since it is not economical. Similarly, from an economic point of view, slopes 7% or greater costs for the construction are much larger than the plain areas (Ayan 1985).

During the decision making process beside the construction properties, the transportation considerations are important too. As an example it is well known that the planning rules permits a maximum 12% slope in the roads even though a bus can climb up to a 20% slope (Ayan 1985). So in the design of the inclined areas these properties must also be taken into account.

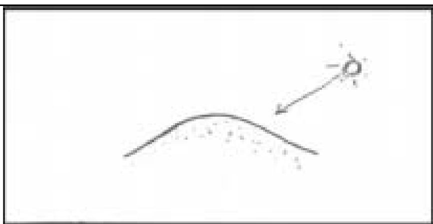
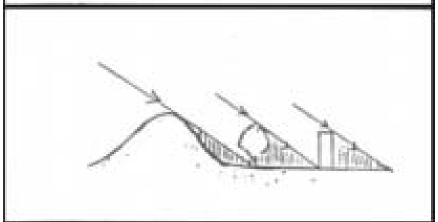
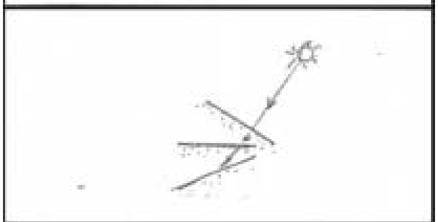
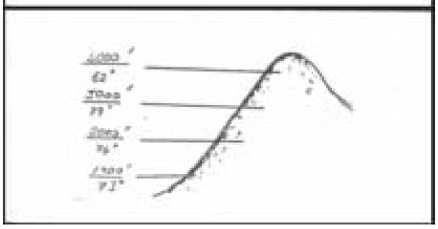
| | |
|---|---|
|  | South-facing slopes are exposed to more sunlight than north-facing slopes. |
|  | The form of land, building heights, trees or other objects that may affect the duration of daylight shadows they create. |
|  | The inclined area where solar radiation reaches at higher angles is heated up more than other surfaces. |
|  | Temperatures change depending on the height. It reduced by 1.6 degrees every 308,4 meters higher. The rate of the temperature increases at night. |

Figure 4.1. The effects of the topography on solar radiation.
(Source: Lechner 1991, 35)

When the inclinations direction and magnitude are evaluated from an energy point of view, the passive solar effect becomes the main focus. With increasing altitude, the temperature decreases, but the solar radiation and the speed of the wind increases.

The direction of the inclination is also very important from a microclimatic point of view. The spacing between the buildings on the north hand side of the incline must be increased because the solar effect is higher on the south side of the incline. The shadowing effect is also larger on the north side than the south side. When the inclined surfaces are compared with the plain areas, it is seen that the length of the shadow of the building on the south side of the inclination is shorter than the plain areas. This is vice versa in the north areas. On the other hand, generally the west sides of the hills are warmer than the north side of the hills since the average temperature in the afternoon is higher than the morning. Such conditions directly affect the decision making process and energy efficient urban design characteristics (Aydemir et al 2004, 415)

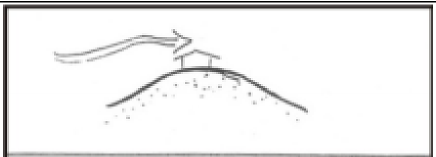
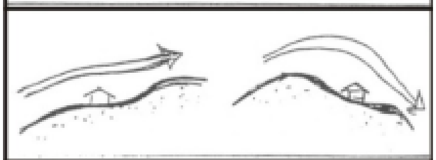
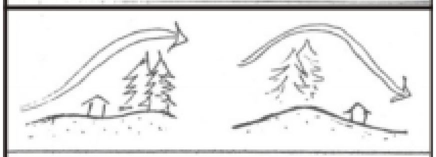
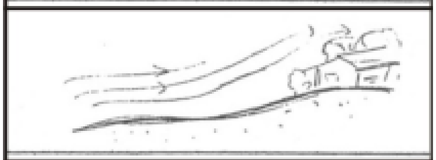
| | |
|---|---|
|  | The top of the hills are unprotected against the winds |
|  | The proper settlement area can protect the building from the effects of the winds |
|  | The effect of the wind can be minimized by using existing planting or new planting |
|  | The effects of the wind can be minimized by soft landscapes |
|  | A natural air circulation can be formed by using proper urban design and planting |
|  | Some landscape forms can cause turbulence for the wind |

Figure 4.2. The effect of topography on the air movements.
(Source: Lechner 1991, 37)

Considering the magnitude of the inclination, it is seen that from the energy efficient design point of view, small inclinations are favorable since the solar effect can be easily used in a more efficient way. Compared to the plain areas, this is especially true on the southern sides of the inclines. On the other hand, considering the north side of the inclination this situation became worse. The inclinations between 8 to 20% are optimal for energy efficiency in settlements. While not forgetting the additional cost of construction in inclined areas and the limitations for transportation when the slope is higher than 10% (Ayan 1985).

The topography is another important parameter on the heating and cooling loads of the urban areas and buildings. The lower part of the hill that faces south is desirable in cold climates to avoid cold winds. On the other hand, for hot climates, the upper parts of the hills are favorable to increase the winds cooling effects on the buildings.

### 4.1.2. Climate

In the mass housing projects, to evaluate the environment effects and energy efficiency, the local climate factors and microclimatic effects should be identified in detail. This is because climate and microclimate effects have priority in energy consumption.

For sustaining a balance in urban planning with nature and climate, usage of fossil fuels, pollution, and the heat island effect must be minimized. Likewise, a suitable habitat must be formed for more comfortable life in today’s cities. Discussion of the climate effects must be included in the prevailing decision strategy for climate friendly building designs (Figure 4.3).


Figure 4.3. Climate regions in the world.
(Source: Rosenlund 2013)

Zeren et al. (1987), Gürsel (1991), Orhon et al. (1988), Akşit (2005) categorize five different climate regions for Turkey: cold climate region, mild-dry region, mild-humid region, hot-dry region, and hot-humid region. Another classification belongs to Ayan (1985) as: cold climate region, mild region, Aegean region, hot-dry region, and hot-humid region. In his study, Göksu (1999) classifies seven different climate regions: cold climate region, mild-dry region, mild region, mild-humid region, hot-dry region, hot-humid region and mixed region. In this dissertation, the first classification with five different climates is assumed and energy efficient design parameters are compiled according to the relevant literature based on climate region.

In some areas, such as Izmir where this case study is done, establishing settlement in the thermal zone is favorable. However, in clement climate areas, establishing settlements in the upper parts of the hills are favorable because winds remove the negative effects of humidity at elevation (Tokuç 2005).

Design and planning parameters for hot-humid climates for Izmir are tabulated in (Table 4.1).

Table 4.1. Design and planning parameters of hot-humid climate regions.
(Source: This table is formed by compiled studies; Olgyay 1973, Ayan 1985, Owens 1986, Givoni 1998, Tokuç 2005, Karaca 2008 and Ovalı 2009)

| | |
|---|---|
| Cities | Adana, Antalya, Aydın, Denizli, Hatay, **Izmir**, Manisa, Mersin, Muğla, Osmaniye |
| Aim | The general aim is to avoid overheating and radiation in hot periods and increase ventilation and humidity losses. |
| Settlement Pattern | Higher sections of the hills must be selected to increase the cooling effects of the winds. |
| | Separate and scattered formation must be selected with a preference for shadowed, short streets. |
| | Necessary spacing must be supplied between the buildings to ease the winds cooling effect |
| | To increase the ventilation effect of the wind buildings must be placed in a dislocated way |
| | Open spaces must be designed in the path of the winds for sake of a well ventilation |
| | Layout design must be in a way that the wind corridors must be maintained. |
| Building Design | Scattered buildings must be designed with lower density and a north-east building orientation |
| | Shadow protection must be applied on the roof and higher storey buildings placed in south east and west. |
| | North facades must be maximized and west facades must be minimized for the sake of cooling in the nights |
| | Necessary arrangements must be applied to ease the penetration of the ventilation through the building |
| Orientation | 5°-10° from south through east |
| | 3° from south through east is optimum. Good orientation is from 10° southwest to -19° south east, acceptable orientation is 19° from southwest to -30° southeast |
| Open Space | Public spaces must be shaded |
| | Elements that may cause an increase in evaporation must be avoided |
| Planting | Use of water elements is preferred |
| | Wide branched, long body trees must be used for sustaining a well wind corridor. Grass and shaded places must be formed around the buildings in the hot season |
| | Short plants and shrubs must be avoided near the buildings since they block the ventilation |
| Form | East and west facades must be minimized for sake of decreasing radiation |
| | Optimum building ratio 1:1,7 and 1,3 in east and west direction. |
| Facades and Openings | Openings and windows must be maximized in the direction of ventilation for a better cooling performance |
| | On the other hand, to decrease the solar radiation the windows and openings must be minimized in the solar orientation. |
| Materials and Colors | Light colors must be preferred for solar radiation<br>Materials that have resistance to humidity must be selected along with a good insulation property |

### 4.1.3. Solar Radiation

Sun has many important functions in the energy based studies of urban environment since it is crucial for lighting and heating. Proper use of the solar radiation will decrease the heating loads in cold seasons, but effective protection from sun is needed by sheltering or other ways in order to decrease the cooling loads.

The magnitude and time of solar radiation are directly effect the amount of heat gained by the building. The influence of the sun should be well estimated in land-use planning and housing design stages. Turkey has a great solar energy potential (Table 4.2), thus for decreasing the heating costs of buildings, this potential must be taken into consideration.

Table 4.2. Turkey's monthly solar energy potential.
(Source: EIE 2013)

| Month | Monthly total solar energy ($kWh/m^2$ month) | Sun period (H/ month) |
|---|---|---|
| January | 51.75 | 103 |
| February | 63.27 | 115 |
| March | 96.65 | 165 |
| April | 122.23 | 197 |
| May | 153.86 | 273 |
| June | 168.75 | 325 |
| July | 175.38 | 365 |
| August | 158.40 | 343 |
| September | 123.28 | 280 |
| October | 89.90 | 214 |
| November | 60.82 | 157 |
| December | 46.87 | 103 |
| Total | 1311 | 2640 |
| Average | 3.6 | 7.2 |

The amount of the solar radiation depends on various factors such as: atmospheric conditions, altitude, and angle of the sun, humidity and latitude.

The altitude effects the intensity of the solar radiation and increases the heating capacity of the sun. Moreover, the atmospheric properties such as humidity, clouds and dust effect he solar radiation. The main consideration is that the particles and molecules in the atmosphere that blocks the sun's light will decrease the intensity of the solar radiation.

The latitude of the location is another important factor for solar radiation. An increase of latitude means the area is getting closer to the equator. This results in the sun having an angle with the earth's surface. This increases the heating capacity.

In the winter season for both cold and warm climates, the sun light must reach the building in an unblocked way to increase the heating effects. Likewise, the orientation of the building must be adjusted to increase solar gain. In these areas open spaces and windows must be increased to let the sunlight reach further into the building. The selection of window glass is also important regarding these concerns.

In hot climates, on the other hand, and especially in the summer months, the heating effect of the sun gradually increases the cooling cost of the building. In such areas small openings and windows with reflective glasses must be selected. The orientation and building size ratios must be well discussed in order to minimize the solar gain and costs of cooling.

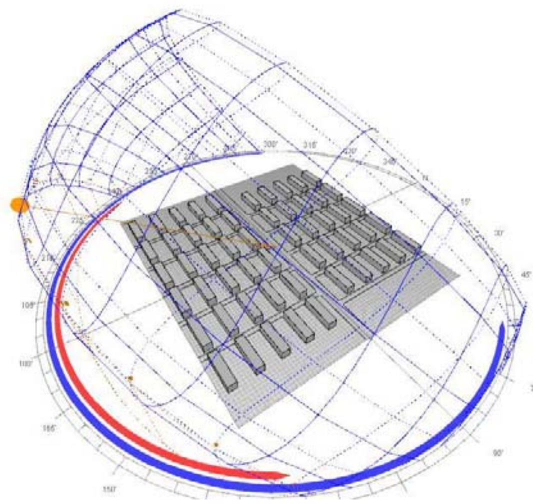


Figure 4.4. Changing position of the sun during a year.
(Source: Ecotech 2013)

Another important effect on the solar radiation and sunlight is the shadow. Shadowing must be taken into consideration in a comprehensive manner and proper spacing between the buildings must be maintained accordingly. The shadow lengths of the buildings and other urban elements depend on the time, date and latitude.

Figure 4.4 shows the path of sun through the year for a sample urban district. As it is seen in the summer period, especially on the 21st of June sun reaches to the highest angular value with maximum heating capacity. Conversely, the lowest value is on December 21st in the winter. Depending on these dates, the shadow lengths are maximum in the December 21st and minimum in June 21st.

### 4.1.4. Temperature

Outside temperature is one of the important design parameters from an urban design point of view. There are various parameters which effect the temperature of the air in an urban area. Examples of such parameters are: latitude, sun position, climate, topography, altitude, season, wind and humidity.

The temperature scale of the urban area directly effects the constructional elements chosen. Such elements are insulation, building formation, layout of the buildings and height of the buildings.

Lower temperatures require high insulation elements on the walls, doors, roofs and windows. On the other hand, the heating system selection is also very important in these areas since some heating systems cannot be used in low temperature zones such as heat pumps.

### 4.1.5. Humidity

Humidity is also effective on the heating and cooling loads of an urban area. It is the amount of water content in the air, and is inversely proportional with the temperature. It decreases overheating and overcooling. Additionally, it decreases the temperature difference between day and night. Humidity is also another indication of the comfort in buildings and an urban area. Humidity generally has higher values in the areas near a body of water like a sea and a lake. Humidity also is higher, around forests and rainy places. The selection of construction material and the buildings form are affected when considering humidity, especially for the sake of an efficient and comfortable design. Hard materials and materials that do not store moisture must be chosen for humid areas. The humidity must be taken under control especially in the urban areas where settlements are presented. The optimum humidity ranges for residential areas lies in between 40 to 60% (Soysal 2008). It is important to note how humidity effects solar radiation. While looking at humidity values in the same latitude, the areas with high humidity values have lower solar radiation values compared to the non humid areas. This happens since humidity (water molecules) blocks the sun light and decreases its effect on the earth.

### 4.1.6. Wind

Air flows from hot and high pressure areas to low pressure and cold areas. This movement forms the winds. For a comprehensive energy conservation the effect of winds on the system must investigated in detail. In hot climates the winds can be used to decrease the cooling loads by using its refreshing and evaporative effects. On the other hand, winds can increase the heating loads in cold climates by infiltrating through the doors and windows and by increasing the heat transfer from the surfacing by increasing the heat transfer coefficient as a result of increased turbulence.

In the design of buildings and urban areas, the difference in the direction and magnitude of the winds are crucial from an energy perspective. In cold climates the short façade of the buildings must face the prevailing winds. Also a decreasing of the surface areas increases the conservation of energy in cold climates.

Similarly another important factor in the design is to consider the chimney effect and unwanted air flows though the buildings and the urban area.

Winds are one of the climatic effects on air temperature and pressure. The winds direction and magnitude is very important for reaching a sustainable comfort level in urban areas. The effect of the wind on these areas and the buildings depends on some characteristic parameters of the wind (Ovalı 2009). Examples of these are wind direction and its characteristics (hot, cold, humid, dry), speed, time, building form (compact, spread apart etc.), topographic properties, urban land form, buildings surface materials properties (roughness).

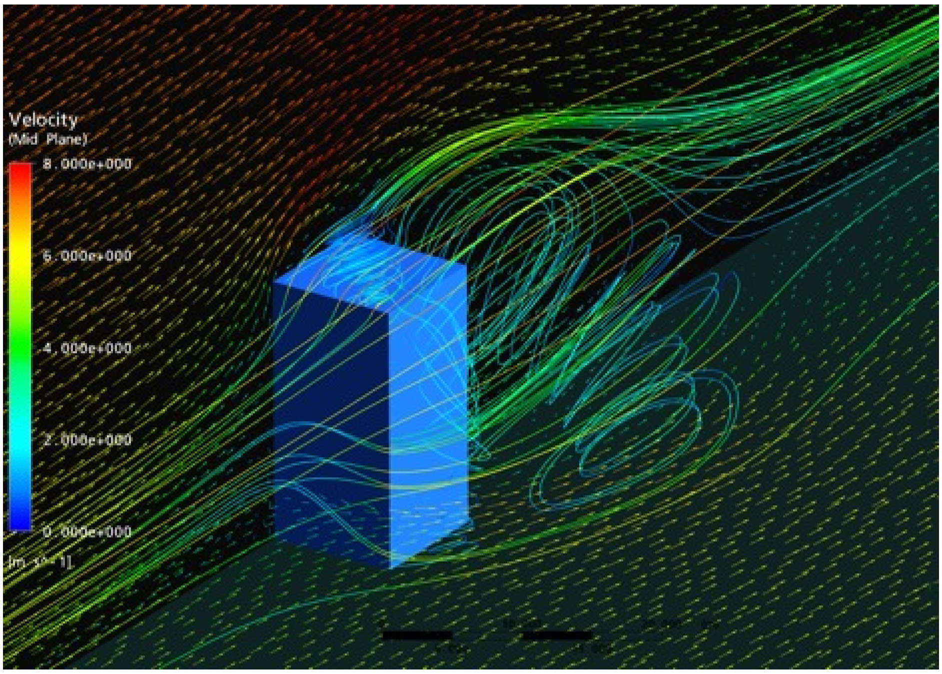



Figure 4.5. The path of wind around a building.
(Source: LMU 2013)

Golany (1996) points out that ventilation is essential for hot-humid climate cities. Generally winds coming from a body of water, such as a lake or sea, or winds at higher elevations, are cooler than those in the lowlands.

The speed of the wind also changes depending on the inclination of the area. It can increase up to 60% with an inclination of 6-20%. Moreover, in the hot period the air will flow through the upper side of the hill and in the cold period, cooler air will flow through the downside of the hill.

Wind speed is also affected by various elements in the topography and the urban environment. The widths of the streets and openings in the urban area, the height of the buildings, and the formation of the layout all have direct effect on the wind speed. As the area that the air flows is decreasing, the speed of the air will be increased. This is a well-known fluid mechanics fundamental (Figure 4.5). In this respect, it is easy to understand that the design of the layout is deeply effective on the energy performance of the buildings because of with increasing speed the outside convective heat transfer coefficient of the buildings will increase. This situation is seen also with increasing height of the buildings. It is well-known fact that, when altitude increases, the wind speed increases. A similar situation is caused as the width of the streets and the increasing building heights leads to an increase in the heat loss from the buildings. In addition, the turbulent effect of the wind behind the building must be remembered since it greatly increases the heat losses as a result of the increasing heat transfer coefficient (Figure 4.6). Considering these, interactions are very important from a design point of view (Hisarlıgil 2009).

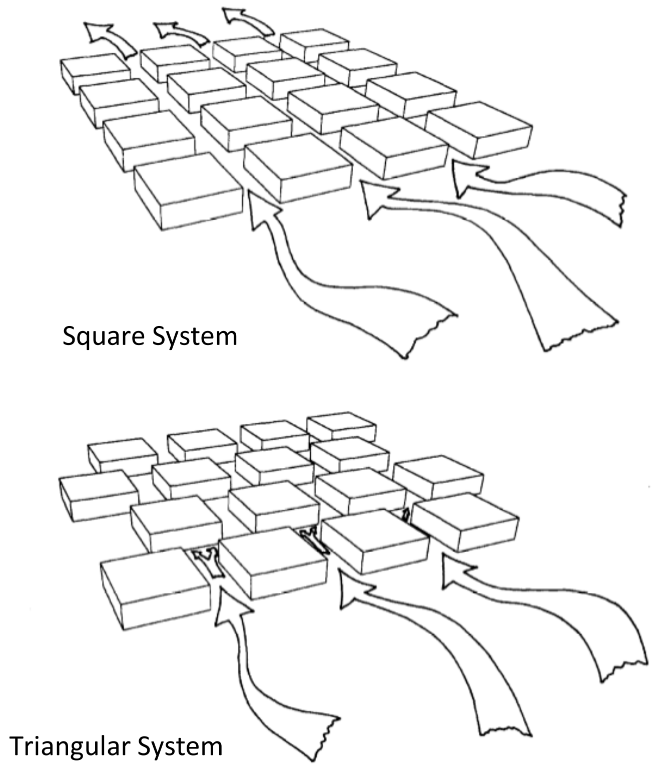



Figure 4.6. Effect of layout of streets on the wind penetration through the city.
(Source: Golany 1996, 462)

The impact of the buildings' height and layout is seen in Figure 4.7. The turbulent flows behind and between the buildings are seen clearly and the effect of height on the turbulence and speed can be interpreted as well.

Another important characteristic is the orientation of the buildings towards the prevailing wind. If the building is faced towards the prevailing wind the ventilation effect is maximized but the heat loss is also increased. This situation is desired in hot climates. A 45° of angle from the prevailing wind direction can lead to a 50% decrease in the wind speed (Givoni 1998).

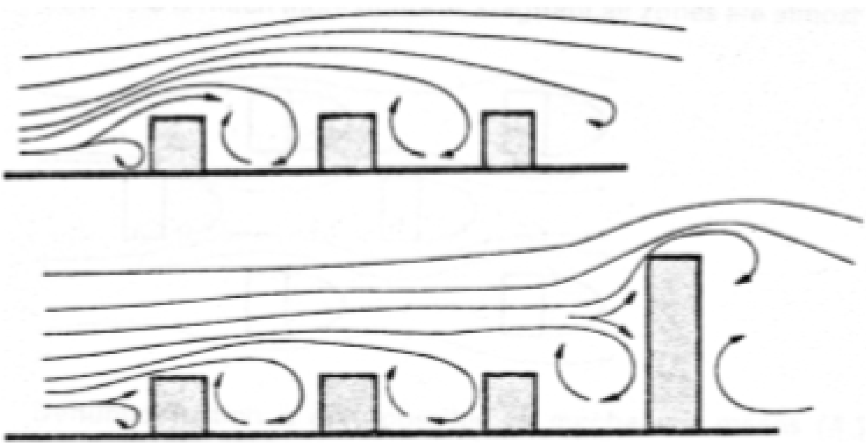


Figure 4.7. Effect of wind on the building layout.
(Source: Ovalı 2009, 79)

Maintaining proper building orientation increases the comfort in the buildings because of the winds support (Tokuç 2005). The spacing and layout of the buildings must be well designed in order to increase the cooling effect in hot climates and decreased in cold climates. The spacing between the buildings must be increased; the buildings must not be placed parallel to each other to sustain an equal wind effect on every building.

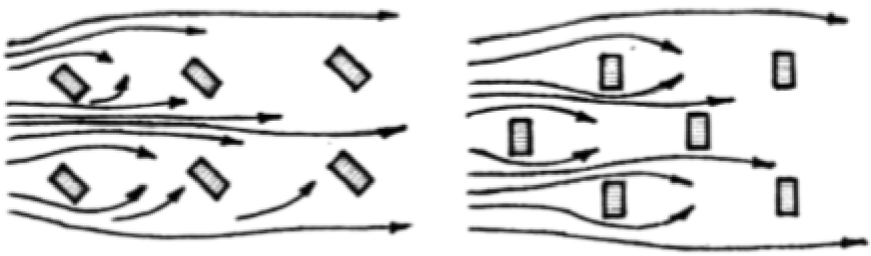


Figure 4.8. The effect of layout on winds.
(Source: Ovalı 2009, 81)

### 4.1.7. Landscape and Planting

The landscape and plants can be used for energy effectiveness. They can be used in the arrangements of humidity, shadowing and blocking winds. To reach this aim local property such as the wind directions and magnitudes, the path of the sun throughout the year must clearly be understood. The plants properties should also be deeply assimilated.

Landscaping is very important as it can be very effective for removing or increasing the effect of the wind, solar radiation, noise pollution, air pollution and the particles in the air. Trees and green spaces especially contribute to cooling and balance the humidity in the air done by partial evaporation and a lead to a decrease in temperature which is important in hot seasons (Santamouries 2001). Moreover, by controlling the ground temperature with green spaces, the negative effects of the asphalt, with its slow cooling will be removed. This is especially true at night for hot climates.

Proper usage of planting may greatly affect the urban area such as;

- Decreasing the solar radiation up to 90%
- Decreasing wind speed 10%
- Decreasing ground temperature for 7 ºC near the buildings
- Balancing high night temperatures
- Decreasing the energy needs of the buildings up to 40% (Colombo et al. 1994).

In the cold climate areas, the always green thick planting can protect the area from the negative effects of the wind and can increase the prevention of heat loss. Deciduous plants are also favorable when solar radiation is wanted in winter.

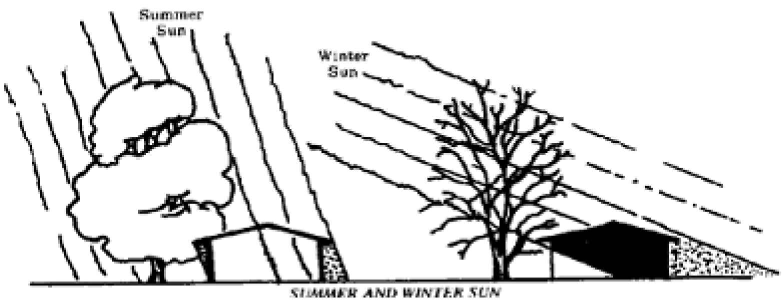



Figure 4.9. Effect of deciduous trees in summer and winter.
(Source: Walker and Newman 2009, 2)

Shadowing is the main parameter of the landscaping for buildings. As seen in the Figure 4.9, deciduous trees must be selected for managing the shadow. This is especially the case in areas where shadow is needed in the hot season and is not wanted in the cold season. Proper planting depends on the type and height of the plants.

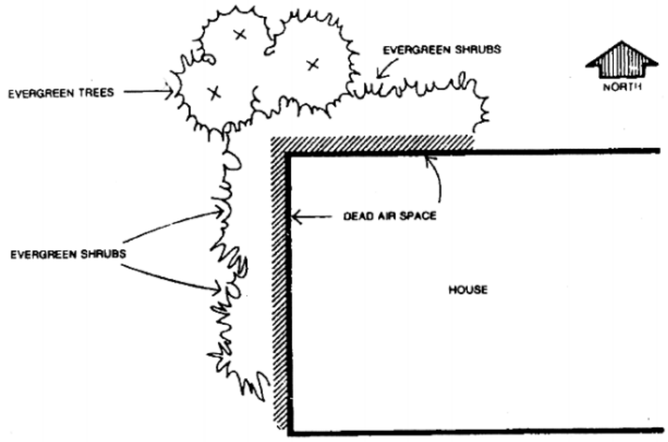



Figure 4.10. Foundation plantings to create dead air space.
(Source: Walker and Newman 2009, 3).

Wind controlling is another important parameter from a landscaping point of view. The investigation on the Great Plains has shown that up to 25 % of energy savings for heating is possible from windbreaks (Walker 2009). Planting evergreens can change the directions of the cold winds away from the building if it is placed in the proper location (Figure 4.10, Figure 4.11). The height of the trees will be an important parameter for calculating the distance from the building. The higher the height of the tree, the longer the distance can be given away from the building (Canan 2008).

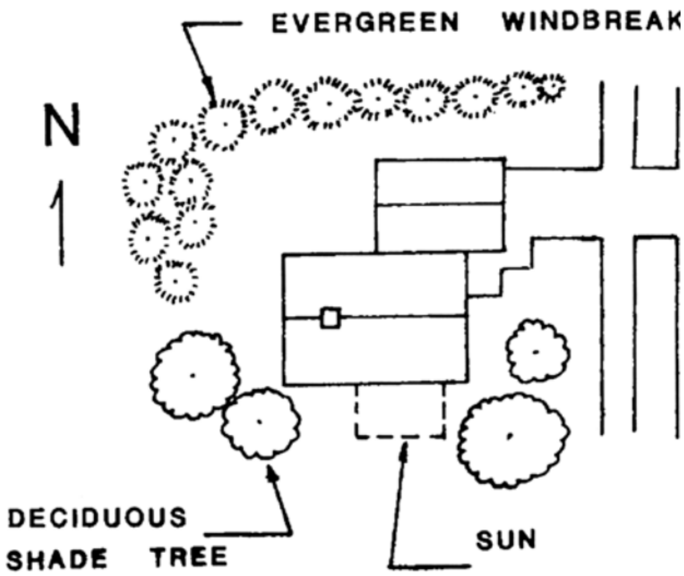



Figure 4.11. Suggested locations for windbreak shade trees and sun pockets.
(Source: Walker and Newman 2009, 3)

By arranging the landscaping in a proper way the shadowing and windbreak properties can be used together allowing some openings can then be designed for letting the sun come through in wanted areas (Figure 4.11).

## 4.2.Built Environment Parameters

In the design of the built environment the conservation of energy should also be taken into account. The purpose of this is for decreasing the heat demand as well as for sustaining comfort properties. These include the properties of the buildings, construction material of the buildings and the relationship of the buildings with each other.

### 4.2.1.Layout Effects on the Built-up Area

For sustainable energy efficient design, not only the natural properties of the area are important, but also the surrounding urban texture. These two factors combined together affect the energy performance of the buildings. The most important factor about the layout and urban texture is the density of the area (Figure 4.12). It directly affects the energy consumption and design characteristics. In the cities with higher density, the air temperature is higher but wind speed is lower (-25%); this is different from the rural areas (Soysal 2008).

Figure 4.12. The effect of distribution of the buildings with respect to height on wind directions through the city (Source: Ministry of Economy Baden-Württemburg 2008, 5).

Bodies of water, another urban texture feature, also effect the cities temperature profile. This is due to how the heat absorption capacity of a body of water is high and also the effect of evaporation leads to an increase in the humidity. When other structures, whose heat absorption capacity is low, like roads and buildings, are taken into consideration, the large difference in temperature between the day and night is notable. Their likely temperature increment in the day time, especially in summer, will be an unwanted result in hot-humid and hot climates. On the other hand, air conditions are different in the cities where more dry and polluted air (low solar radiation) is presented. In dry rural areas, however, the air is clean (free of molecules, particles) and have a higher humidity. These properties will effect the energy conservation directly.

### 4.2.2. Orientation

Orientation determines the amount of solar radiation reaching the surfaces of the buildings and urban area. As solar radiation penetrates through the surfaces of the building (i.e. walls, windows), it may decrease the heating loads of a building in the winter and increase while possibly increasing cooling loads in summer. The effect of the solar radiation is comprehensively discussed in Chapter 4.1.3. Depending on these, the selection of the proper orientation becomes very important. The selection of orientation of the building from an energy point of view may vary depending on various properties such as; latitude, altitude, climate, water body and topography.

In simple structures, a southward orientation is the most valid application. With developing technology, however, new ideas can prevail and the direction of the building can be altered depending on the usage and the size of the building. Basically, optimum direction is selected by considering the amount of solar radiation at the highest value on the 21st of January and the lowest value on the 21st of July (Berköz 1983, Tokuç 2005). For example in Izmir, the detailed analysis with the method of Olgyay resulted in an orientation of 12 degrees from the south toward the east as the optimum orientation In Olgyay's method, the land's temperature and humidity values are evaluated for ten years. Based on this the appropriate orientation is evaluated by the position of the sun. In other words, the amount of solar radiation reaching the horizontal surfaces is calculated and the optimum direction is selected where the solar radiation amount is lowest for the cooling period and highest in the heating period.

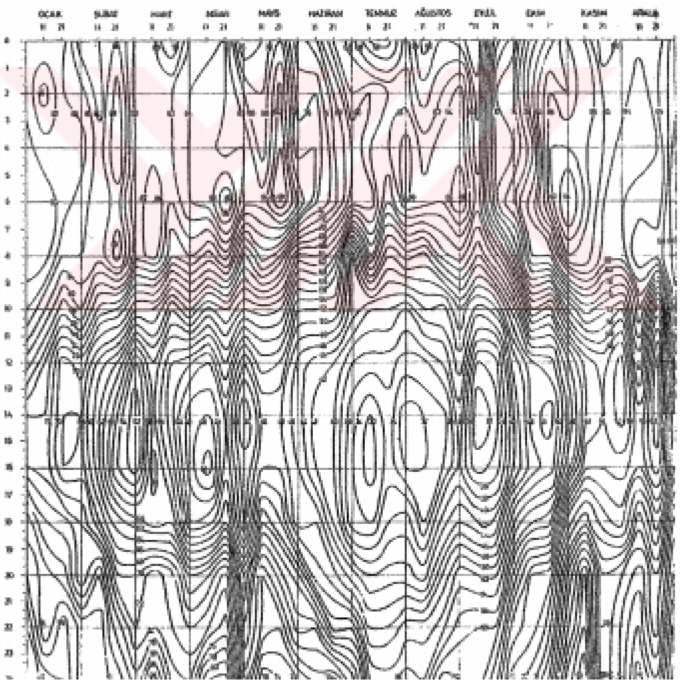


Figure 4.13. Relative humidity curves for Izmir.
(Source: Zeren 1967, 21)

In order to decrease the heating and cooling loads of the buildings proper orientation must be selected during the design phase (Figure 4.13, Figure 4.14). This is done, in a way that the shadowing effect will be minimized and benefits from the wind will be maximized. There can be a maximum of 60% energy consumption reduction achieved by considering the wind direction in the orientation of the building according to Ovalı (2009). This can be aided by arranging the orientation of the settlements and buildings in the winds direction and a staggered placement will increase benefits from the wind. However, when doing this, the orientation and localization of the building must be optimized in a way to avoid increasing the heating loads.

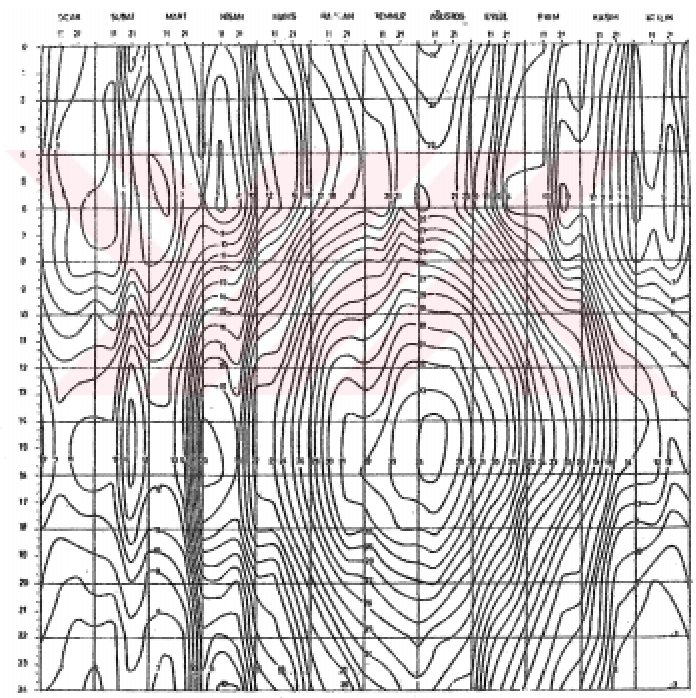
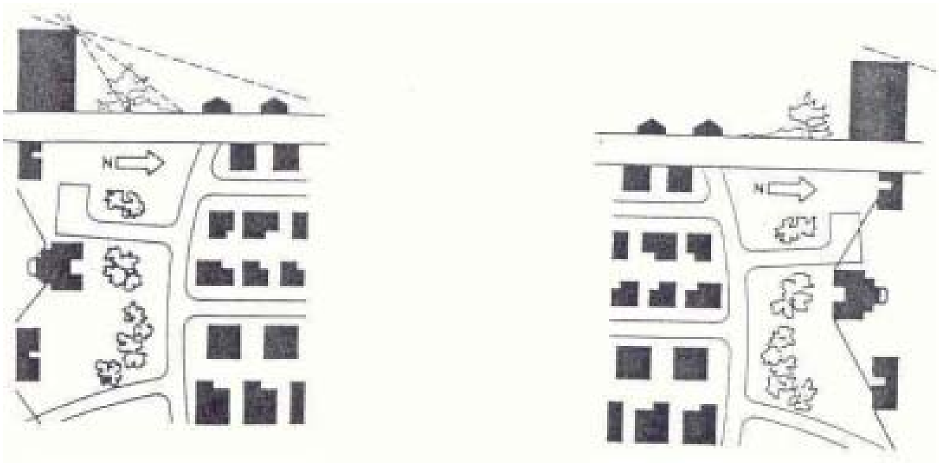


Figure 4.14. Average temperature curves for Izmir.
(Source: Zeren 1967, 23)

The solar energy usage in the buildings and urban area can be maximized when the space between the buildings are equal or larger than the maximum length of the shadow of the building (Figure 4.15) (Soysal 2008). The heat loss amount can be affected with the placements of the buildings. This must especially consider well in compact structures.




Negative Example Positive Example

Figure 4.15. Development plan and the use of solar energy.
(Source: Schafer and Weigert 1997, 15)

### 4.2.3. Location

The localization of the buildings is important for climate control, avoiding air pollution, heat gain and loss and when considering the effect of physical environmental factors. These factors are the location, direction, inclination of the area and solar radiation values. One of the most important parameters is the amount of solar access on the surfaces of the buildings. Also the effects of the winds cannot be underestimated. In respect to this, the location of the building and the settlement area is very important from energy performance points of view and an optimum position must be maintained regarding these effects.

### 4.2.4. Building Form

The form of the building is another significant parameter of energy efficient design. The form of the building largely affects heating and cooling loads. The energy efficient design of one building is crucial in a building block when all of the buildings are energy efficiently designed and that will have great contribution to the local and global energy conservation and reduction in the emissions. Building form is defined by the ratio of the length to the width of the building, height, roof inclination and type, the inclinations in the facades and etc. The volume to surface area relation is also another parameter which has effect on the loads of the building.

Simple geometrically shaped small buildings are favorable from energy point of view without underestimating the fortitude and strength. Also small buildings have small surface areas that will decrease the heat loss to the surrounding which will directly decrease the heating load and cost (Figure 4.16) (Çalışkan 2007). Beside the smallness, simplicity is also another important factor from usage that effects the energy usage by occupants.

The selection of the form of the buildings depends on various parameters and the decisions must be made according to these parameters. Main parameters are; latitude, wind condition (prevailing winds, speed of winds), solar radiation.

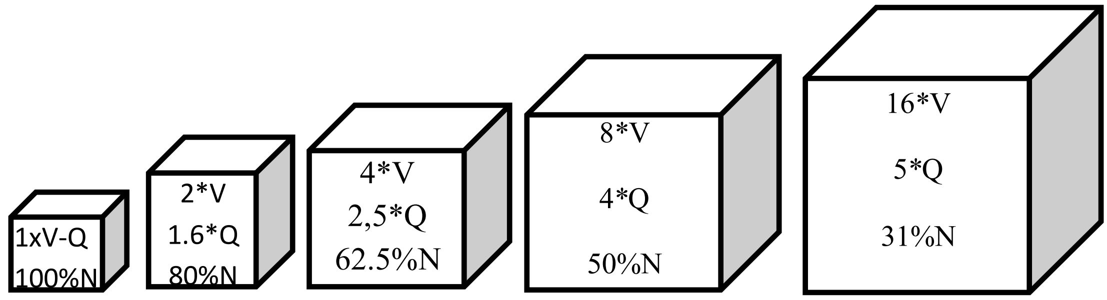



Figure 4.16. Decreasing heat loss with increasing form factor.
(Source: Tönük 2001, 24)

Generally buildings with low form factor values are desirable since the amount of surface area relatively low with respect to the volume of the building that leads compact buildings to be preferred. These types of buildings are energy conservative since low surface area results to low heat loss from the walls, roof and floor to the ground. Especially in the mild and hot climates, these types of buildings have application area greatly (Canan 2008).

On the other hand, compact buildings have some difficulties such as low ventilation and daylight access. This situation may lead to a trade of between the compactness and comfort, so an optimization study may be applied in this field.

Height is another factor that is effective in the design of energy efficient buildings. The heat loss is higher in tall buildings mostly because of faster and colder winds in the high altitudes.

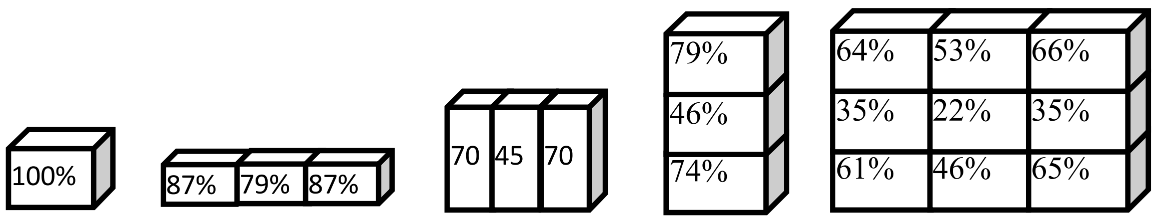



Figure 4.17. The effect of united volumes on the heat loss.
(Source: Tönük 2001, 26)

If the aim is energy conservation, low but terraced buildings must be preferred and these buildings must be faced towards south for sake of increasing solar radiation (Soysal 2008). In the

Figure 4.17 it seen that up to 88% of energy can be conserved depending on the form of the building.

On the other hand, for urban settlements with higher cooling needs, this type of compact buildings are not favored. Therefore, in hot-dry and hot-humid climates sparse settlement is advised. However, for mild climates this situation brings a trade off on the decision making process and an optimization is needed.

Table 4.3. Building forms for various climates.
(Source: Olgyay 1973, 93)

| Climate | Building Form | |
|---|---|---|
| | Optimum Ratio | Maximum Ratio |
| **Cold** | 1:1.1 | 1:1.3 |
| **Mild-Humid** | 1:1.6 | 1:2.4 |
| **Mild-Dry** | 1:1.1 | 1:1.3 |
| **Hot-Humid** | 1:1.7 | 1:3 |
| **Hot-Dry** | 1:1.3 | 1:1.6 |

The building form ratio for various climate zones is demonstrated in the Table 4.3. Generally the wider facade of the building is faced toward the sun in all climate regions for sustaining the solar radiation, but the length of it differs depending on the climate.

### 4.2.5. Distance Between Buildings

The distance between the buildings directly effects the solar radiation and wind from an energy point of view. Buildings are obstacles to the wind, changing its direction and speed. The distance and height of the buildings is crucial when the shadow effect of one building to the others is considered (Table 4.4).

Similarly the space between the buildings must also be adjusted in a way so that the sun light can have access to all the buildings and the beneficial winds are not blocked (Table 4.5).

Shashua-Bar et al. (2004) have shown that the temperature in the building is affected by the distance between the buildings. When the distance is decreased to 0.67 H, the temperature rises 2 K in a building.

Table 4.4. Optimum distances depending on the wind and sun for various climates. (Source: Orhon et al. 1988, 11)

| Climate Zone | According to the wind (In the direction of prevailing wind) | According to the Sun (North – South direction) |
|---|---|---|
| **Cold** | Z-5H | 1.5-2.5 H |
| **Mild-Humid** | H-5H | 2-3 H |
| **Mild-Dry** | H-5H | 2-3 H |
| **Hot-Humid** | 5-7 H | 1.5 H – 2.5 H |
| **Hot-Dry** | 1.5 – 2 H | 1. 5 – 2 H |
| **H = Height of the building** | **Z= Ground** | |

The factor of distance between buildings is important in the urban areas where the area is scarce but the need for buildings is high. When the heating is important the buildings must be placed in a way that each building can access solar radiation in a maximum manner. On the other hand, when the cooling is important it is crucial that leaving enough distance in between buildings is considered in order to allow the wind to pass through all of the buildings.

The distance of the buildings must be calculated using the solar data on the 21 st of December in which the sun is at the lowest angular value with the earth (Ratti et al. 2005).

Table 4.5. Optimum height and distances with respect to the buildings stories. (Source: Göksu 1999, 52)

| Storey | H (m) | Distance (m) |
|---|---|---|
| 2 | 6 | 11.8 |
| 4 | 12 | 23.6 |
| 6 | 18 | 35.4 |
| 8 | 24 | 47.2 |
| 12 | 36 | 70.8 |

### 4.2.6. Building Envelope and Insulation

Building envelope is construction materials that are vertically, horizontally and inclined direction which separates the inside of the building from outside. Energy conservation and comfort of the buildings is mostly sustained by these. The optical and thermo-physical properties of the building envelop characterizes the passive heating and cooling properties of the building since the heat gain by solar energy and heat loss from the walls are all happening in this envelop. So the construction material and insulation elements must be selected in a proper manner for reducing the heating, cooling and lighting loads.

### 4.2.7. Natural Ventilation and Solar Control

In order to use climate properties such as wind effects and solar radiation in the buildings some control systems must be used. Natural ventilation is crucial in the buildings to decrease the cooling loads, supply enough fresh air for the sake of occupant health and sustaining comfort conditions.

The direction and size of the openings in the buildings affects the magnitude of the wind effect on the building. The openings must be in opposite directions especially in hot-humid zones (Gouilding 1992, Tokuç 2005).

# CHAPTER 5

# CASE STUDY: MAVISEHIR

In this chapter, a case study is described. To understand the case areas comprehensively, first the climatic characteristics of Izmir such as temperature and wind; and then Mavişehir Mass Housing Project's brief history, area size and building information are provided. In the following sub-sections of this chapter, the exergy analysis results of the existing design are discussed in details. Following these, the proposed design alternatives are developed according to the energy efficient design criteria. Finally, the exergy analyses of the proposed design alternatives are conducted and the results are discussed.

## 5.1.Data for Izmir

Izmir is located 38.25° north and 27.09° east and a hot-humid climate where. The summers are hot and dry whereas the winters are mild and rainy. With reference to climate or geographic characteristics, both the solar potential and the wind potential of Izmir are noticeably high because of the long seashore and various topographic instruments.

### 5.1.1.Temperature

The temperature profile of Izmir is shown in Table 5.1. As can be seen, while July and August are the hottest months in Izmir with temperatures of 27.3ºC and 27.6 ºC respectively, the coldest months are January and February with temperatures of 8.6 ºC and 9.6 ºC respectively (MGM 2013).

### 5.1.2. Wind

The prevailing winds in Izmir come from the southeast and the west (MGM 2013 and Serin 2011). According to district in the city, the wind's direction and gale forces are measured at different levels. For example the wind direction in Güzelyalı Station is southeast with 41.2 m/s, in Seferihisar Station, it is in the southeast direction with 32.1 m/s, while Bornova Station is northeast with 25.0 m/s, in Ciğli station northeast direction with 31.8 m/s (Serin 2011). The prevailing winds directions of Izmir –Ciğli are shown in Figure 5.1 and Figure 5.2 in yearly and monthly basis. This station's data is selected as a basis in the study, since the location of it is very close to the case area of Mavişehir. The distance between the station and the case area is approximately 5 km. According to the data of Ciğli weather station, the prevailing wind direction for the heating period is from southeast, north and northeast on the other hand for cooling period the prevailing winds are arising mostly from the northwest as well as the west and north (Figure 5.1).

Table 5.1 Extreme maximum, minimum and average temperatures measured in long period (°C) (Source: MGM 2013).

| IZMIR | Maximum Temperatures | Minimum Temperatures | Average Temperatures |
|---|---|---|---|
| **January** | 22,4 | -6,4 | 8,6 |
| **February** | 23,8 | -5 | 9,6 |
| **March** | 30,5 | -3,1 | 11,7 |
| **April** | 32,2 | 0,6 | 15,9 |
| **May** | 37,5 | 7 | 20,9 |
| **June** | 41,3 | 10 | 25,7 |
| **July** | 42,6 | 16,1 | 27,3 |
| **August** | 43 | 15,2 | 27,6 |
| **September** | 40,1 | 10 | 23,6 |
| **October** | 36 | 5,3 | 18,9 |
| **November** | 29 | -0,1 | 14,1 |
| **December** | 25,2 | -4 | 10,6 |

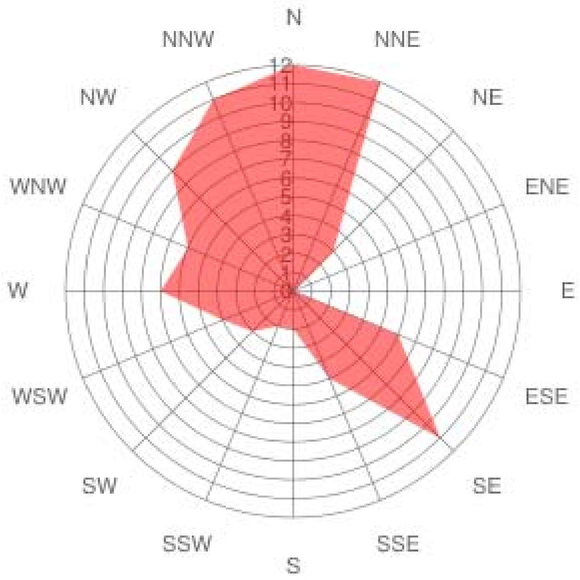



Figure 5.1. The prevailing wind direction in Izmir – Ciğli Station.
(Source: Windfinder 2013)

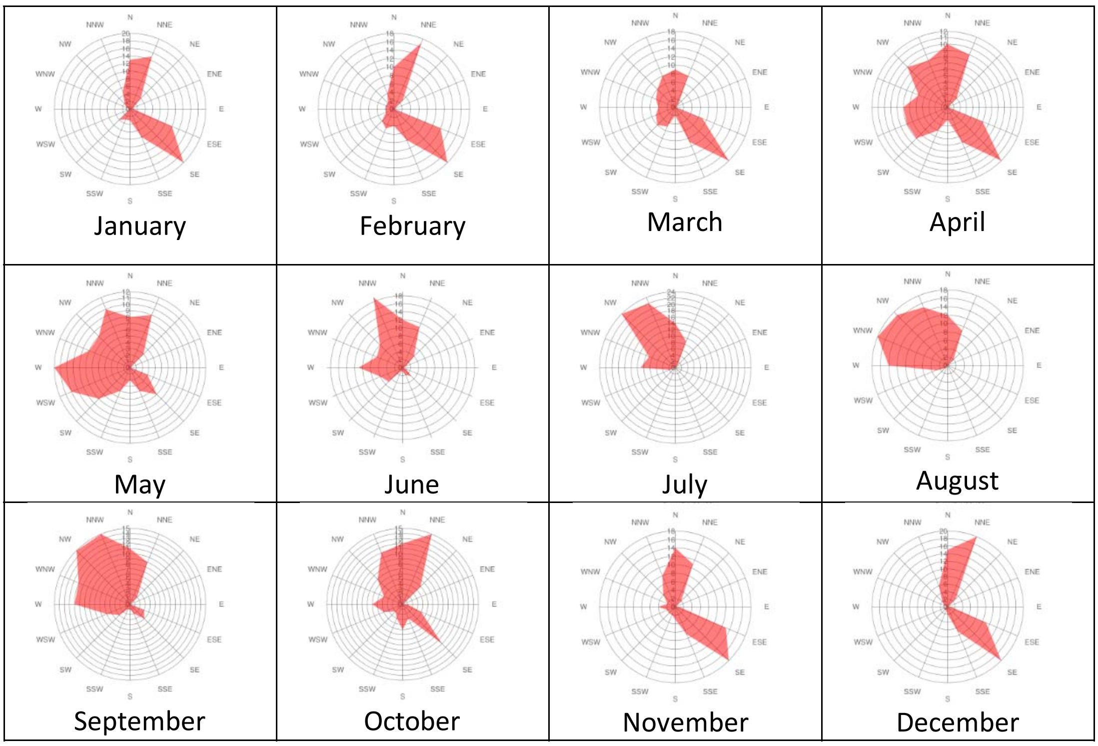



Figure 5.2. Prevailing wind directions in Izmir Ciğli Station through year.
(Source: Windfinder 2013)

### 5.1.3. Sun Path

The sun path diagram of Izmir is given in the figure below. The green curve on the upper side of the diagram represents the path of sun from east to west during the daytime and indicating the angles on 21st June. The blue curve represents the path of sun on the 21st of December. As it is seen in Figure 5.3, the angle of sunlight coming to Izmir varies between the maximum angles of 72° to 29° at 12 pm during the year.

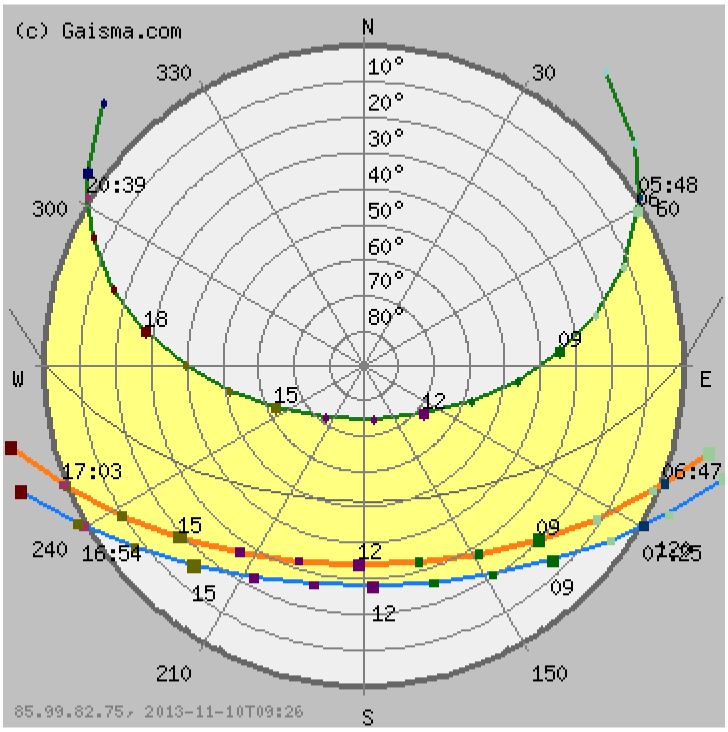



Figure 5.3. Sun path diagram of Izmir.
(Source: Gaisma 2013)

### 5.1.4. Climate of Izmir

One of the well-known studies of Turkey State Meteorological Service was conducted by the, Climatology Department Köppen, Trewartha, Aydeniz, Erinç, Thornthwaite and De Martonne. In this study, climate classifications are investigated and the data gathered from 120 stations location in various cities in between 1971 to 2000 is used for preparing. Turkey's climate classification for every classification map. As for the Köppen's climate classification, Izmir belongs to a mild climate zone with

Mediterranean climate properties which are mild winters and hot and dry summers. For Aydeniz's climate classification, Izmir belongs to a semi dry climate, while for Erinç's climate classification, it is semi-humid climate Martonne classifies it as semi step-semi humid climate, for Trewartha Aydeniz climate classification cool in winters (8.65°C) and hot in summers (27.82°C). Finally, for Thornthwaite's climate classification Izmir belongs to semi-dry, low humid climate with properties from sea effects. (MGM 2013)

Researchers on climate regions in Turkey, Zeren et al. (1987), Gürsel (1991), Orhon et al. (1988), Akşit (2005) categorize five different climate regions for Turkey: cold climate region, mild-dry region, mild-humid region, hot-dry region, and hot-humid region. In another study by Ayan (1985) Turkey is defined regions as; cold climate region, mild region, Aegean region, hot-dry region, and hot-humid region. On the other hand, Göksu (1999) classifies seven different climate regions; cold climate region, mild-dry region, mild region, mild-humid region, hot-dry region, hot-humid region and mixed region.

In this dissertation, the first classification, in which Izmir belongs to hot-humid climate region, is taken into account. Energy efficient design parameters such as building and land-use parameters are compiled according to the relevant literature based on this selected climate region. In other words, this selection depends on the discussions in the literature and this method appears as the best fitting method for the case Izmir. As a result, in the planning and design phase, the parameters depending on hot-humid climate are taken into consideration.

## 5.2. Overview of Mavişehir Mass Housing Area

Mavişehir settlement is located on the boundary of Karşıyaka Municipality to the north of Izmir Bay (Figure 5.4). The case area is defined as a mass housing area with high-rise blocks according to the Metropolitan Master Plan of Izmir (Figure 5.5). The area, totaling 270 ha, is surrounded by Atakent housing units to the east, by old Gediz river bed to the west, by a mass housing area that was previously a squatter housing area to the northeast by Izmir-Manisa-Ankara railway triage area to the north, and by Izmir Bay to the south (Figure 5.6). Mavişehir mass housing area is formed by three sub- regions which were constructed in three stages (Mavişehir I, II and III) (Figure 5.7), with subsidies of the Housing Credit Bank. In addition to the housing units, the projects also includes social and leisure facilities such as sports areas, green areas, parking areas, playgrounds, education and commercial areas. With having a gas central heating system, double glazed windows, sun blinds, decorative coated doors, and double bathrooms; each accommodation in Mavişehir is a luxury residential high-rise apartment and villa (Ozçelik 1998, Koç 2001, Aydoğan 2005).

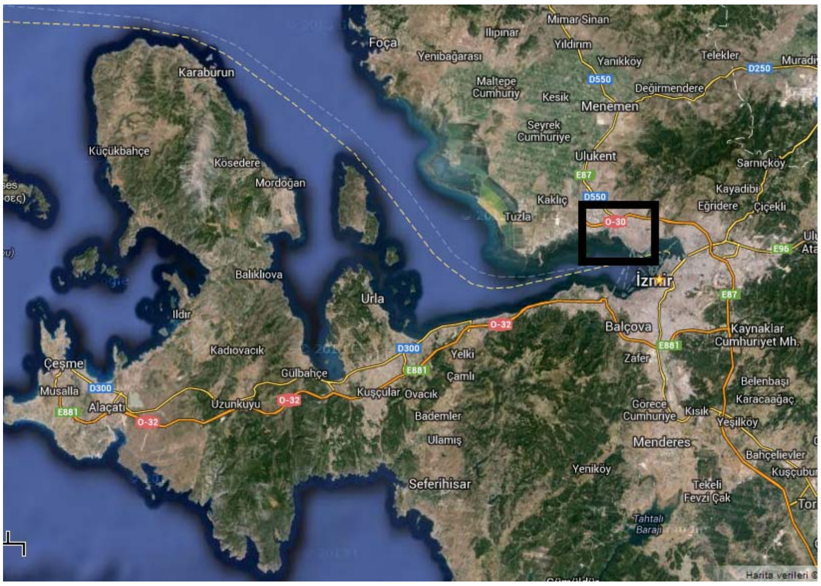



Figure 5.4. Location of Mavişehir in Izmir Bay.
(Source: Google 2013)

Figure 5.5. View of Mavişehir project.
(Source: Google 2013)


Figure 5.6. Aerial view of Mavişehir project in early 2000's.
(Source: Skyscrapercity 2013)

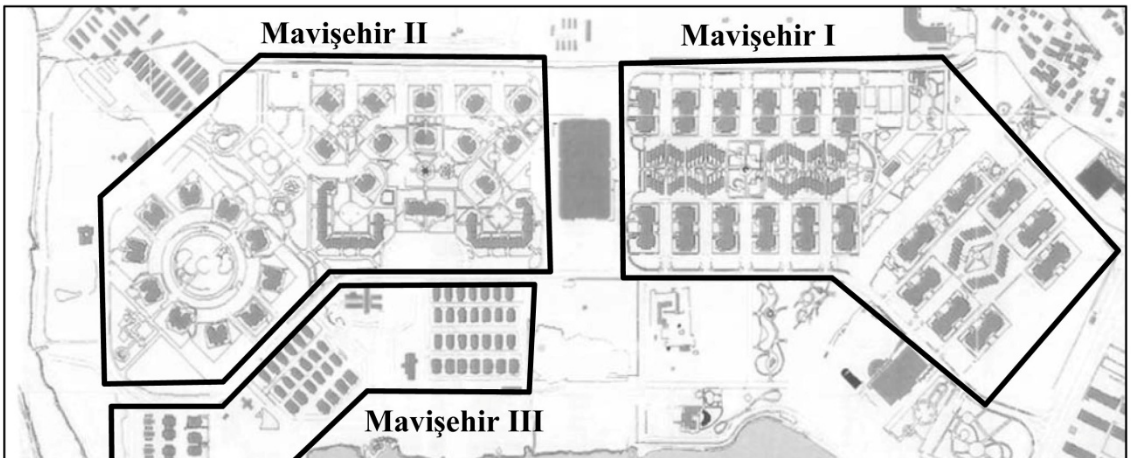



Figure 5.7. Plan of the Mavişehir area.
(Source: Karşıyaka Municipality 2012)

### 5.2.1. Mavişehir I

Figure 5.8. West view of Mavişehir 1 Pamukkale high rises and villas.
(Source: Mavişehir 1 Administration 2013)

The construction of Mavişehir Stage-I began in 1993 and was completed within two years. Mavişehir-I has two building blocks of 260.000 $m^2$, separated by the water canal. The building block has 12 high-rises in the western part, which are called Pamukkale (102.908$m^2$) and eight high-rises in the eastern part, which are called Selçuk (61.474$m^2$). In total there are 20 residential high-rise buildings (2784 flats) and 88 duplex villas that are located in between the residential high-rises (Figure 5.8) (Ozçelik 1998). The high rises have the same building design. Three of the residential high-rises have 16 storeys, ten of them have 18 stores and seven of them have 19 storeys. Each storey has 8 flats. In total Mavişehir I consists of 2872 housing units with a net area between 58 $m^2$-150 $m^2$ with 1 to 4 rooms. The Project has a density of 174 houses/ha and a net population density of 664 person/ha (Koç 2001). The aim of the design of Mavişehir I is that every apartment will have a sea view and fresh air coming from the sea. They air is not going to be blocked because of planned adjusting of the blocks perpendicular to the coast and their west-east direction (Figure 5.9).

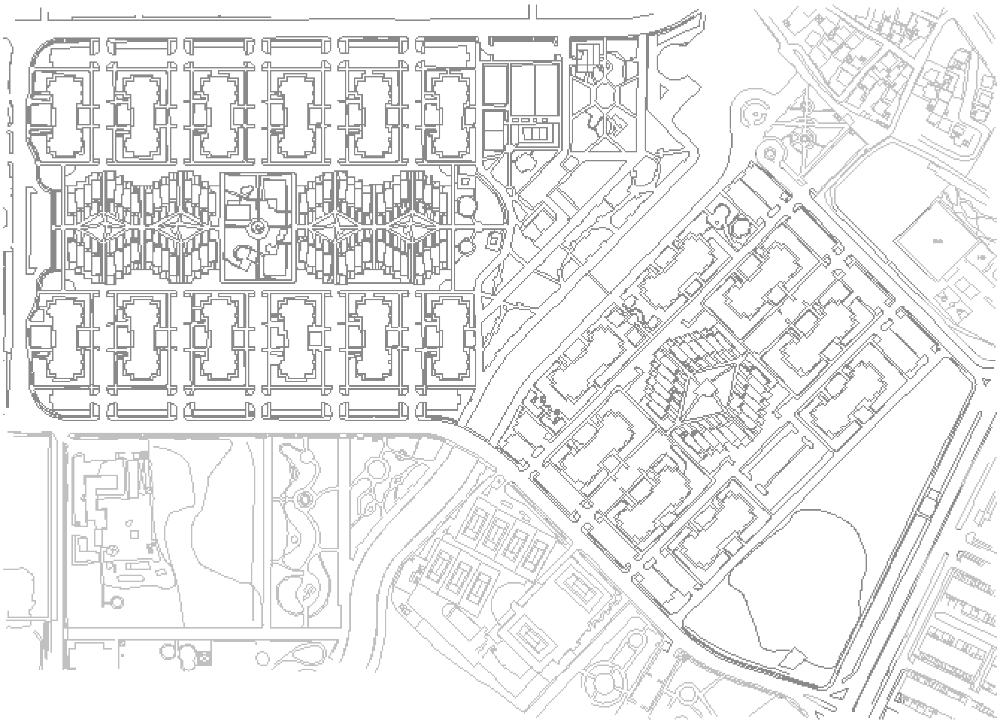


Figure 5.9. Site plan for Mavişehir I.
(Source: Karşıyaka Municipality 2012)

On the other hand, the duplex villas that have been positioned between the rectangular blocks are caught between them and have some problems with visual privacy problems (Sayar and Süer 2004). Moreover, the villas have a significant shadow problem because of the high rise blocks adjacent to them (Figure 5.10, Figure 5.11).

Figure 5.10. View of Mavişehir I Pamukkale high rises from air.
(Source: Milliyet 2013)

Figure 5.11. Green area and playground between high-rises and duplex villas in Mavişehir I (Source: Mavişehir 1 Administration 2013).

### 5.2.2. Mavişehir II

Figure 5.12. View of Mavişehir II Flamingo.
(Source: Peyzajuygulama 2013)

Differing from Mavişehir I, Mavişehir II (Figure 5.12) has different types of blocks with various designs and combinations of high-rises that provide a dynamic built environment. The area consists of four building blocks of 512.803 $m^2$. The construction of this stage was started in 1995 and was completed in 1997.

Figure 5.13. Looking from south to north of Mavişehir II - Albatros.
(Source: Photograph by Yelda Mert)

There are 2448 residential units with a net area between 56 $m^2$-149 $m^2$ and 1 to 4 rooms in 38 residential high-rises. These are called Albatros (Figure 5.13, Figure 5.14), Flamingo, Kuğu, Kırlangıç and Turna. Albatros consists of ten high-rises of 22 storey-buildings. Flamingo blocks are 12 blocks, each of which is a 23-storey building. Only Kuğu has 20 and 22 storeys. Turna, on the other hand, is a combination of seven different plan types of 10 and 14 storeys. Similarly, Kırlangıç is a combination of eight different plan types of 10 and 14 storeys (Aydoğan, 2005 and Ozçelik, 1998).


Figure 5.14. Site plan for Mavişehir II.
(Source: Karşıyaka Municipality 2012)

## 5.3. Proposed Energy Efficient Design Alternatives of Mavişehir Building Block Area

Various parameters are taken into account in new building block design alternatives for the sake of increasing energy conservation and solar gain combined with the selection of more efficient energy systems.

The main design parameters and design perspectives are identified in this section. Three alternative building block designs have been developed with four-storey buildings, eight-storey buildings and solar envelope based model. Additionally, three different plan alternatives are developed for building.

### 5.3.1. Orientation

The orientation of the buildings is selected depending on the aim of increasing solar gain in the winter period. Based on the literature, the heating cost of buildings is as high as cooling, even in Izmir.

For hot-humid regions, the orientation of the building must be adjusted in a position that the long side of the building must face the south with a proper angle eastward. This angle varies from 5° to 10° in various studies, but the result of the Olgyay method is used as a basis in this study. The angle 12° from south towards east is selected as the main orientation (Tokuç 2005) as described in the previous chapter. Moreover, as mentioned the long side of the building faces southward for increasing the solar gain.

### 5.3.2. Building Form

As previously mentioned, the building form is crucial in the energy efficient design and the optimum building form varies depending on the climate. Optimum building form is used as 1:1.7 in this study based on the findings of literature (Olgyay 1973). The width of the building is selected as 30 m and the length is 18m in the design.

The height of the buildings is also important from an energy conservation point of view. By increasing the height the upper storeys, possibility to have strong winds that cause an increase in the heat loss arises. This depends on the increase on the heat transfer coefficient (U). The optimum building height in this study is selected as 12m, with having four storeys to assure compactness while trying to increase the number housing units.

However, to see the effect of the storey number and buildings height another alternative building with 8 storeys and having a 24m height is also studied.

Both 4-storey and 8-storey blocks are designed with four units on each storey.

### 5.3.3. Distance Between Buildings

The spacing allowed between the buildings is mainly important when the shadow effect is taken into account. The buildings' shadow must not block another building's solar input. In order to reach this aim, the calculation used depends on the sun's radiation angle to the earth. In this calculation the value for the 21$^{st}$ of December is used in which the solar radiation's angle is at its lowest in the year. The angle 12:00 pm hour and the value are 29° 12:00 pm is selected because the maximum radiation occurs at noon.

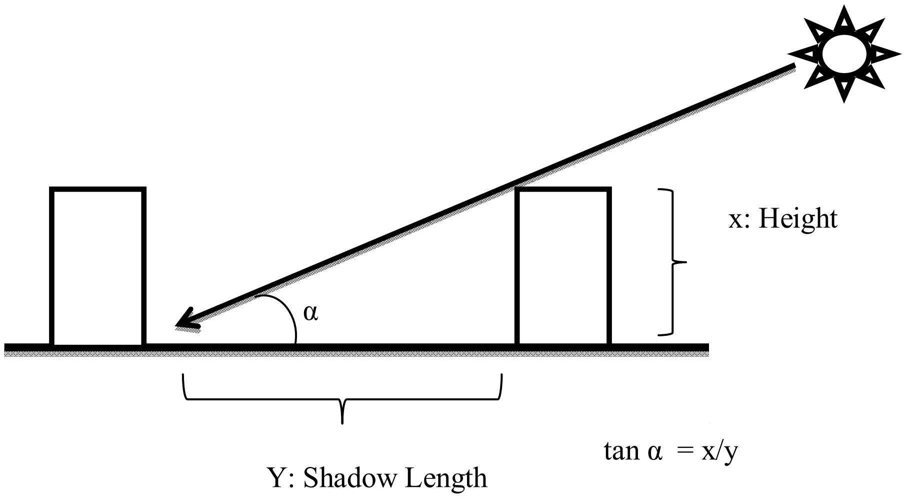



Figure 5.15. The shadow length calculation.
(Source: Prepared by Yelda Mert)

Depending on the calculations, the x / y ratio must be 0.55 and the maximum shadow length is 1.96 times the height of building. This is seen in (Figure 5.15). In this study the ratio of the spacing between the buildings is selected as 2 for the sake of preventing shadow effect. The value is a little higher than the noon shadow length which gives flexibility and increases the solar input to the buildings.

### 5.3.4. Building Organization

In the energy efficient building block design, the organization of the buildings is also important for the sake of increasing the solar input and adjusting the winds effect. Improper locating and the arrangement of the buildings increase the shadow effect factor. For instance, to increase the winds cooling effect on the buildings in the summer and decreasing that effect in winter the period, the organization of the buildings in the building block is developed as shown in Figure 5.16.

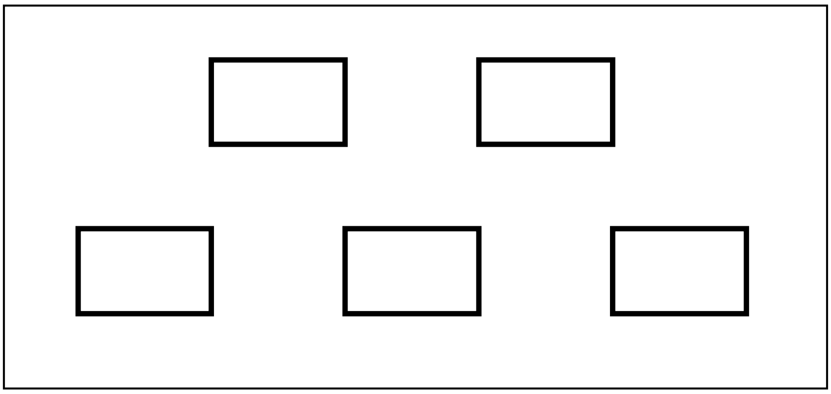


Figure 5.16. The organization of the buildings.
(Source: Prepared by Yelda Mert)

### 5.3.5. Building Envelope and Materials

The building envelope that is the separators between the interior and exterior is very crucial from an energy efficiency perspective. The main element of this envelope is the construction materials chosen for the buildings in the building block. The conservation of energy must be maximized by decreasing heat loss through the roof, doors, windows and walls.

Since the aim in this dissertation is to maximize the energy efficiency, the most insulating material of all material options is selected and used (Table 5.2).

Table 5.2. Heat transfer coefficient values for construction materials of proposed design
(Source: Karşıyaka Municipality 2012)

| **Building part** | **Heat Transfer Coefficient , U [W/m$^2$K]** |
|---|---|
| Roof (insulated) | 0.27 |
| Walls (ventilating brick + insulation) | 0.5 |
| Doors, windows (double glazed) | 0.9 |

### 5.3.6. Landscaping

Landscaping elements water bodies, open green spaces, sports areas and playgrounds are proposed. Water bodies are planned to be used when the cooling effect is needed because of the decrease the effect the difference between humidity and temperature. Plantings and trees are used to prepare shaded spaces. Socio-cultural areas, open spaces and sport area are designed behind the water body that is already present in the case area. In the plan, open spaces are proposed and designed in walking range for all ages. Playgrounds, especially, are designed between the blocks.

Long body and broad-leafed trees are selected for use in the open spaces and car park areas to block the solar effects in the summer period and ease the wind effects.

Besides trees, green crates are used in the parking areas instead of impervious asphalt to decrease the temperature rise in the area and ease the storm water transfer to the soil in rainy periods (Figure 5.17).

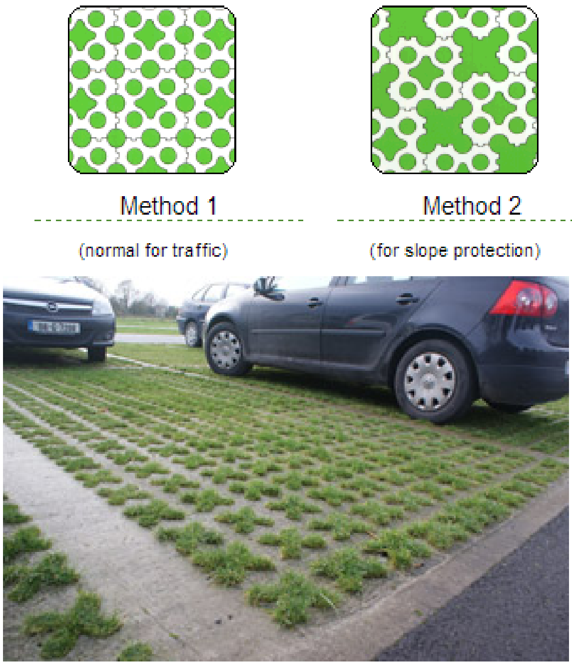



Figure 5.17. Green park area applications.
(Source: Grass Create 2013)

### 5.3.7. Solar Envelope Based (SEB) Design

In addition to the energy efficient design parameters, a criterion for the solar envelop method is integrated in a single method. This hybrid method includes the requirements of orientation, spacing, landscaping and building form as well as the building height properties as proposed in the solar envelop method. The solar envelop method depends on understanding the changing position of the sun throughout the day and year. If this dynamic behavior can be a factor in the design of the urban area, environmental friendliness, sustainability and reduced energy consumption in the cities can be achieved comprehensively (Topaloğlu 2003, Canan 2008 and Knowles 2003).

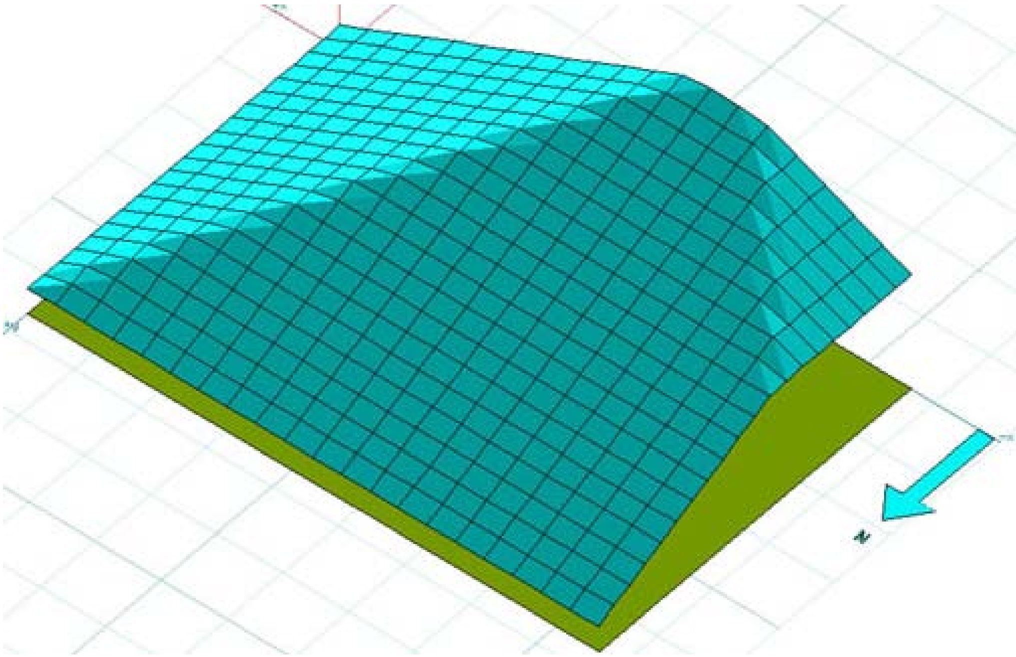


Figure 5.18. Solar envelope method.
(Source: Knowles and Koenig 2002, 3)

The solar envelop method depends on the arrangement of the height of the building(s) in accordance with the suns path when it is in effective hours. Effective sun is the time between 10:00 am and 02:00 pm in which the sun has a heating capacity larger than the other hours of the day. The design is developed according to the angle of sun light in this period (Figure 5.18) (Canan 2008 and Knowles 2003).

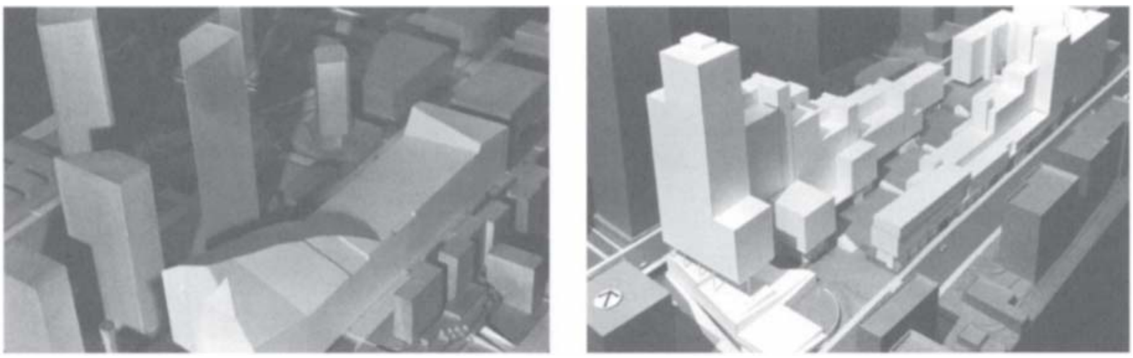


Figure 5.19. Solar envelope method in high-rises.
(Source: Knowles 2003, 13)

A scale impact is aimed in the method and the height is not limited but only adjusted depending on the solar angle and the topography. High-rises can also be applied in this method (Figure 5.19) (Canan 2008 and Knowles 2003). Generally, a terraced structure is the result of this method in building heights or in a buildings singular design.

In this dissertation, a hybrid method is used (Figure 2.20). While the proposed plan alternatives (building form, orientation of buildings, building materials) remain constant, the structure of building block is designed in a terraced structure in accordance with the solar envelope values developed for Izmir and the structure of this model.

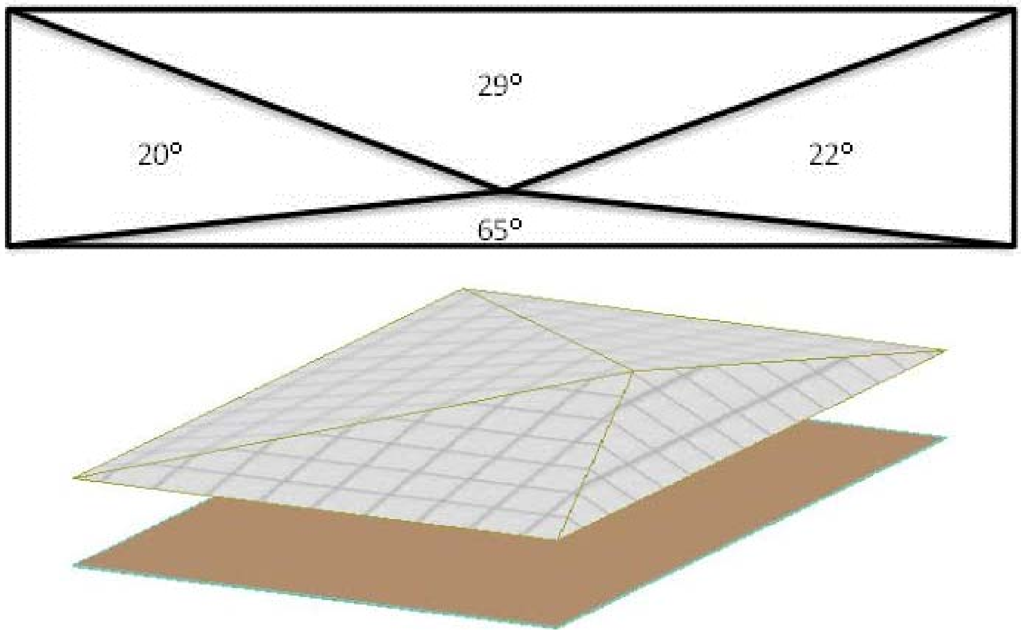



Figure 5.20. Developed solar envelope of the case area.
(Source: Prepared by Yelda Mert)

### 5.3.8. Building Plans

In this study, three different architectural design alternatives for the buildings are proposed by the author (Figure 5.21, Figure 5.22 and Figure 5.23). The building alternatives are designed in a 30m*18m design field that is determined in the building form of the planning phase in this study. Four housing units in each storey are designed and each housing unit is at the corner side of the block that provides a two-facades housing unit for a better solar gain. The areas of housing units for various are between 104 $m^2$ and 117 $m^2$.

The difference between the buildings arises from the openings given in the common areas. A vertical opening is given in the middle of the building for ease of light access to the common areas and proper ventilation in the south-north axis in Plan 1. In Plan 2 the opening for light and fresh access to the building is supplied from the west-east direction with proper windowing. A single facade opening is given in Plan 3 from the south side of the building for allowing enough sunlight into the interior.

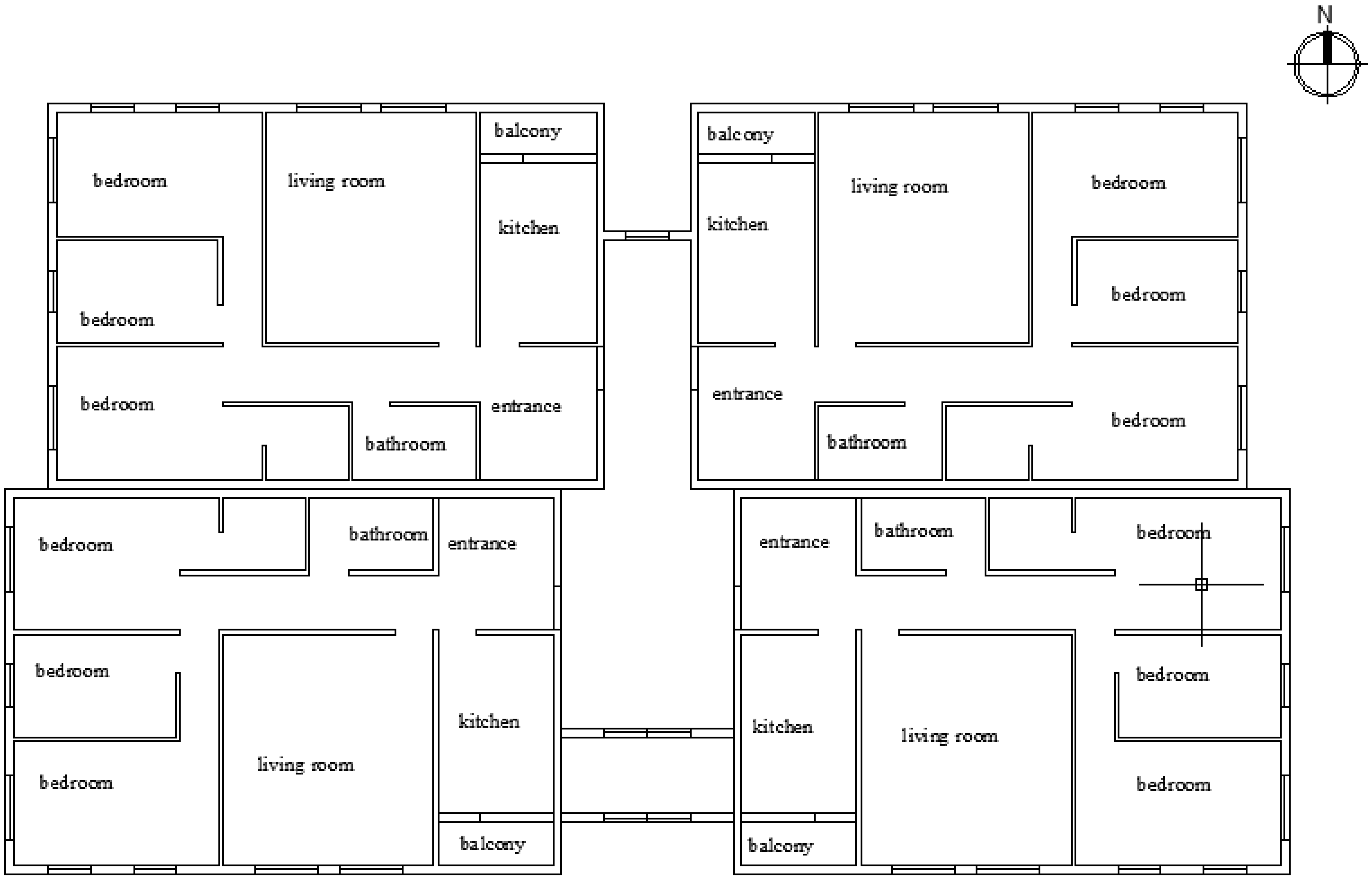



Figure 5.21. Plan 1 for buildings in proposed design.
(Source: Plan is prepared on AutoCAD 2013 by Yelda Mert)

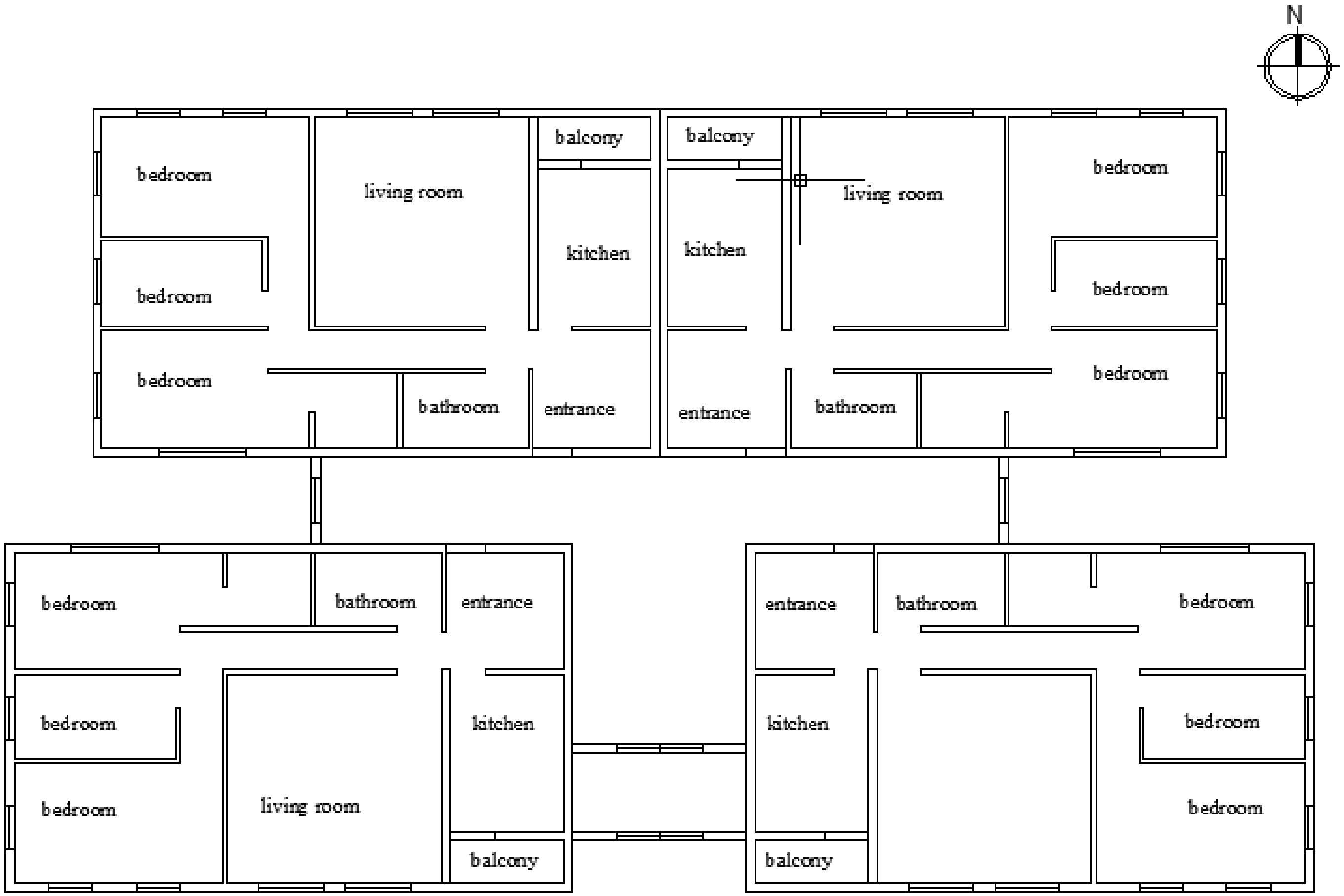



Figure 5.22. Plan 2 for buildings in proposed design.
(Source: Plan is prepared on AutoCAD 2013 by Yelda Mert)

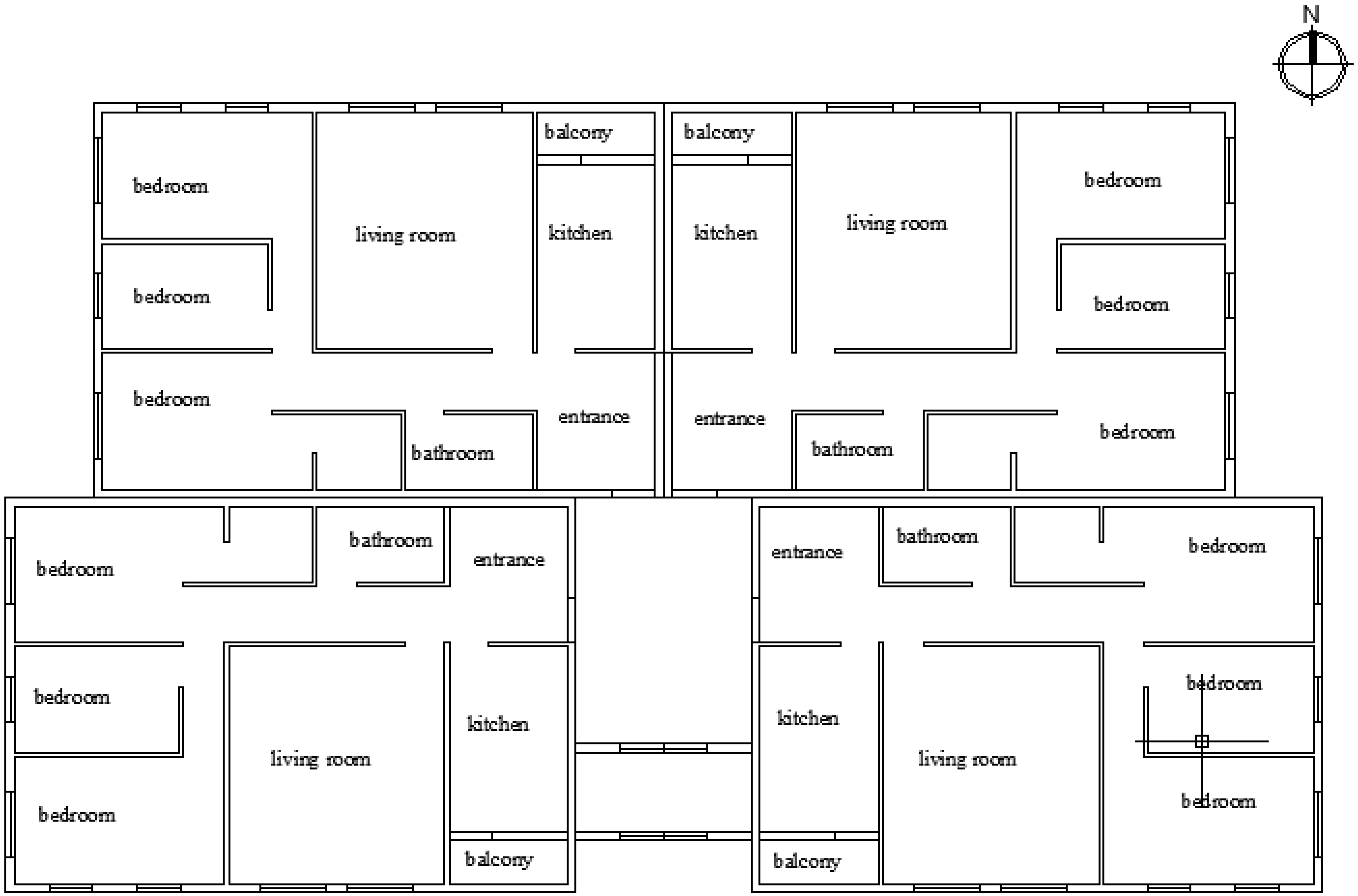



Figure 5.23. Plan 3 for buildings in proposed design.
(Source: Plan is prepared on AutoCAD 2013 by Yelda Mert)

### 5.3.9. Design Alternatives

Three different site plans are proposed for the building block for the sake of investigating the effect of the building height on the exergy performance. Four-storey buildings in the first plan and eight-storey buildings in the second site plan are chosen each having 12 m and 24 m's of height, respectively. In addition to these, a site plan depending on the solar envelop based alternative, is also developed in this section.

Considering the solar, wind and climate factors as described in previous chapters it is concluded that four storey buildings will have better energy efficiency with smaller difference between heating and cooling loads by having a tendency for benefiting the positive effect of solar radiation and winds. As told by Hisarlıgil (2009) for medium storey buildings four and eight storeys are ideal for energy conservation and efficiency since they are used in the proposed design alternatives in this study.

#### 5.3.9.1. Site Plan of Four-Storey Building Block -Alternative A

In the four-storey building block, there are 137 separate buildings each having 16 housing units. There are a total of 2208 housing units (Table 5.3). Green areas, playgrounds, sports area, parking area, social, cultural and educational areas are taken into consideration in the study. The detailed site plans of four-storey plans are shown in Figure 5.24, Figure 5.25, Figure 5.26 and 5.27. The existing building blocks have conserved and new design is applied to this area. The distances between the buildings and orientations of the buildings are arranged according to the energy efficient design parameters. The general and detailed 3-D models of the four-storey plan are shown in Figure 5.28, Figure 5.29, Figure 5.30 and Figure 5.31. As is seen, the distance between buildings and orientation has a positive effect on the shadow effect. The shadows of buildings are not blocking the other buildings solar gain.

Table 5.3. The details about the four-storey plan.

| Storey | Number of Buildings | Number of Housing unit |
|---|---|---|
| 4 | 137 | 2208 |
| **Total** | **137** | **2208** |

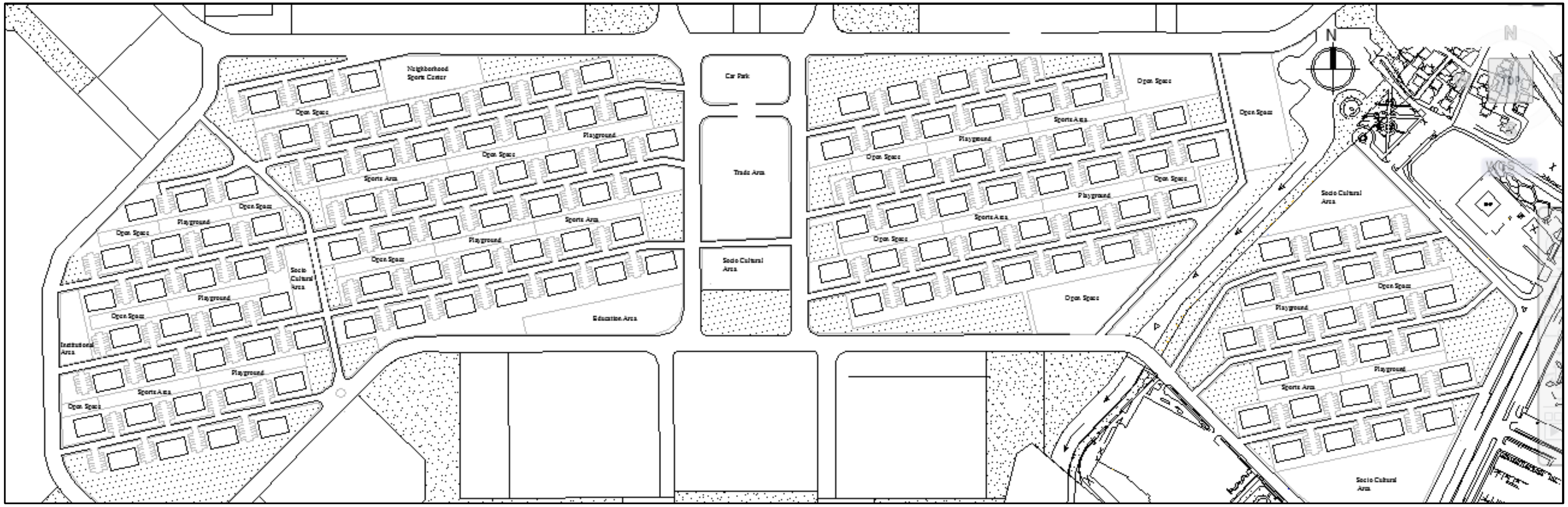


Figure 5.24. Site plan of four-storey buildings alternative (Alternative A).
(Source: Prepared on Autocad 2013 by Yelda Mert)

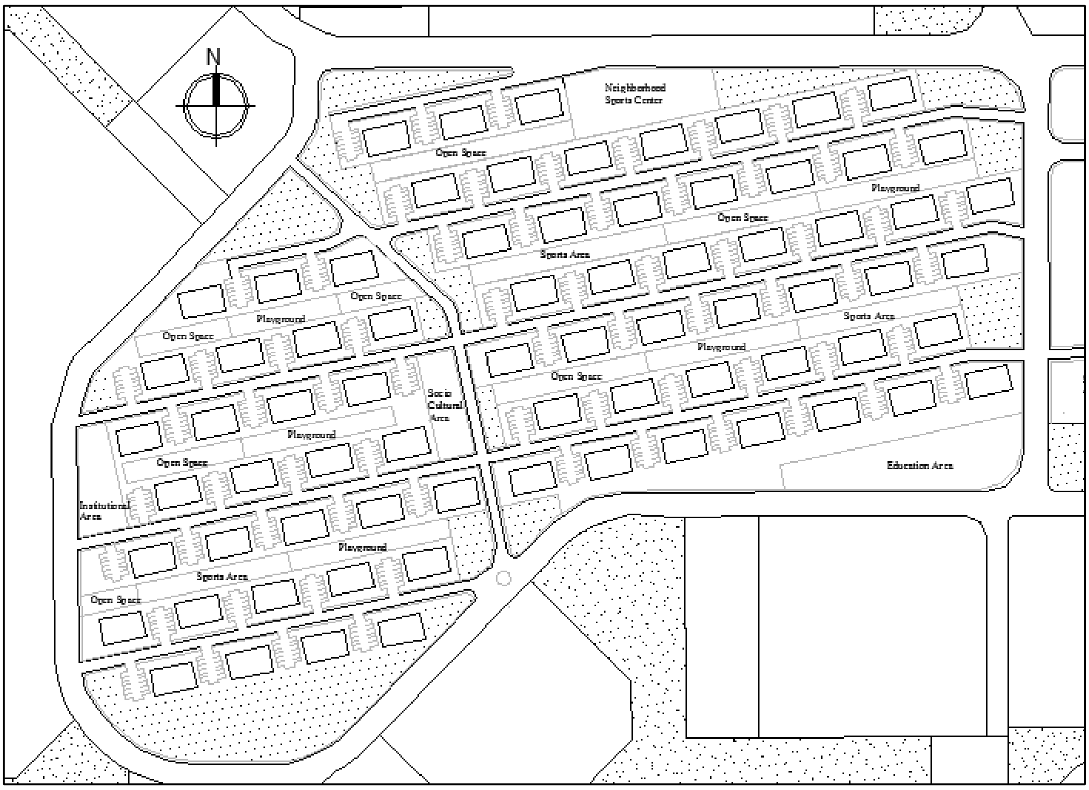



Figure 5.25. Site plan of four-storey buildings alternative (Section 1).
(Source: Prepared on Autocad 2013 by Yelda Mert)

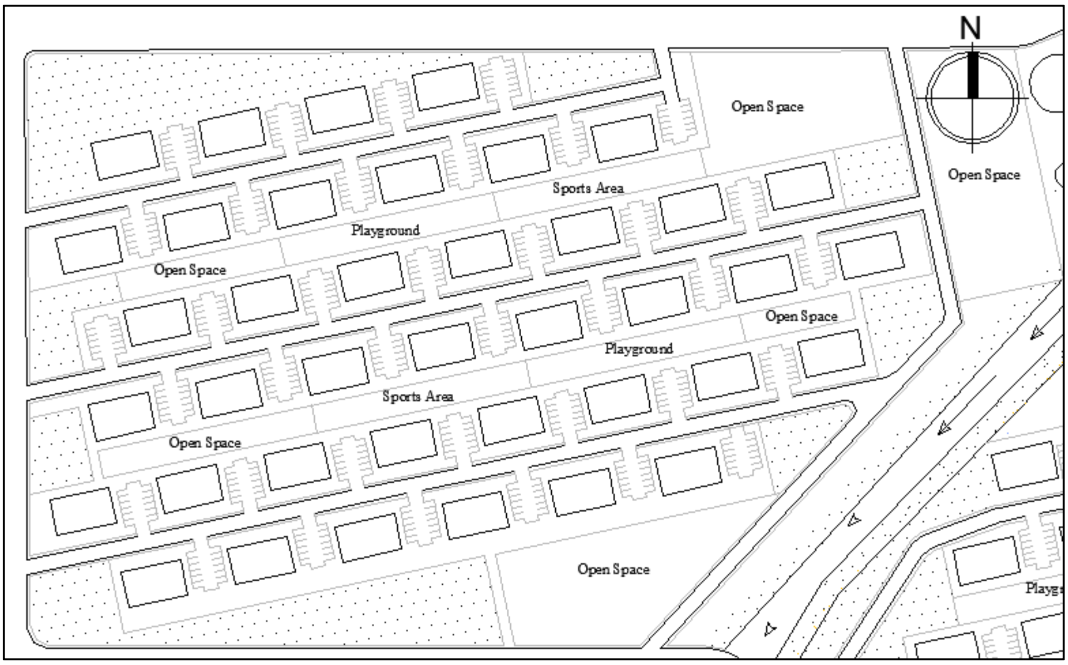



Figure 5.26. Site plan of four-storey buildings alternative (Section 2).
(Source: Prepared on Autocad 2013 by Yelda Mert)

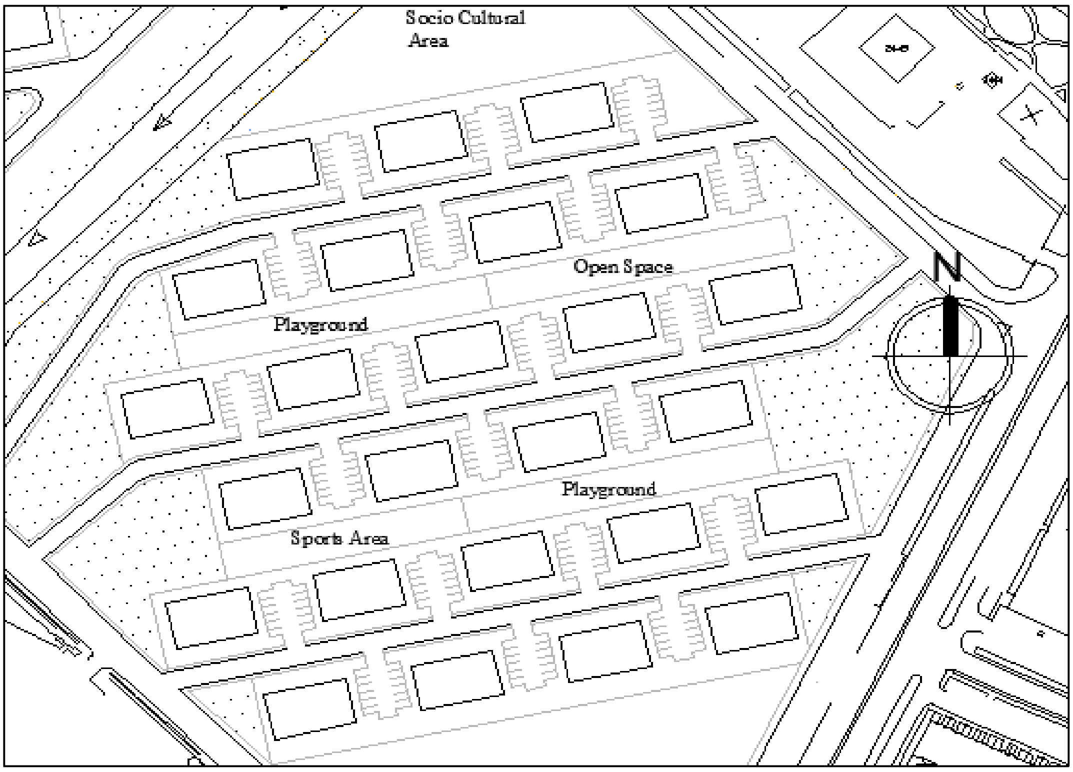



Figure 5.27. Site plan of four-storey buildings alternative (Section 3).
(Source: Prepared on Autocad 2013 by Yelda Mert)

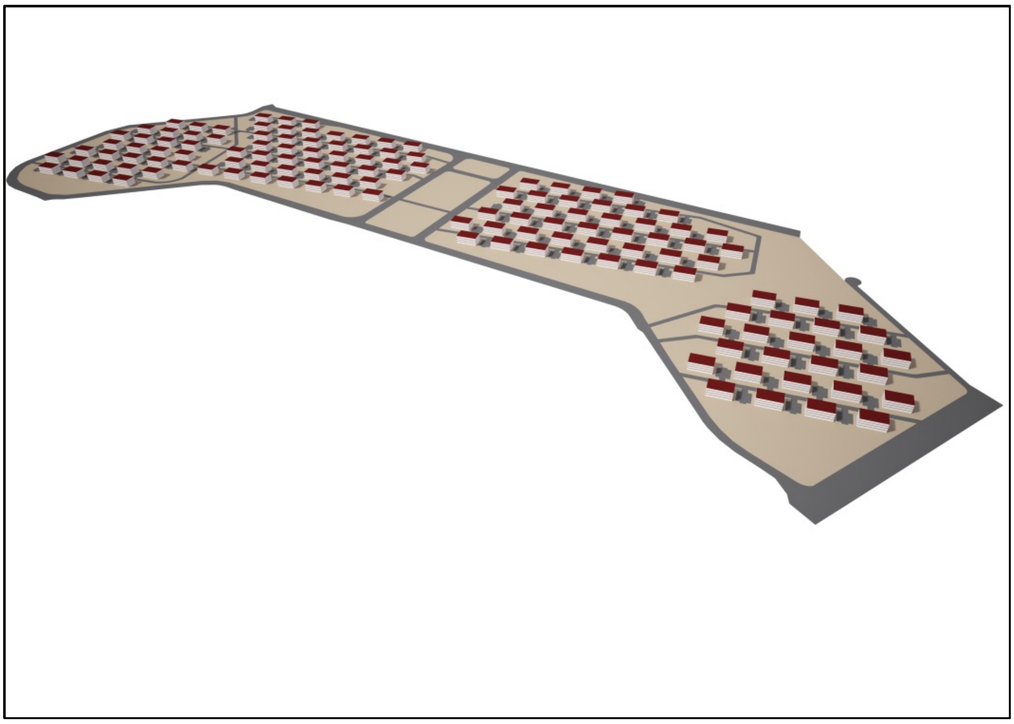


Figure 5.28. Site model of four-storey buildings alternative.
(Source: Prepared on Autocad 2013 and Archicad 17 by Yelda Mert)

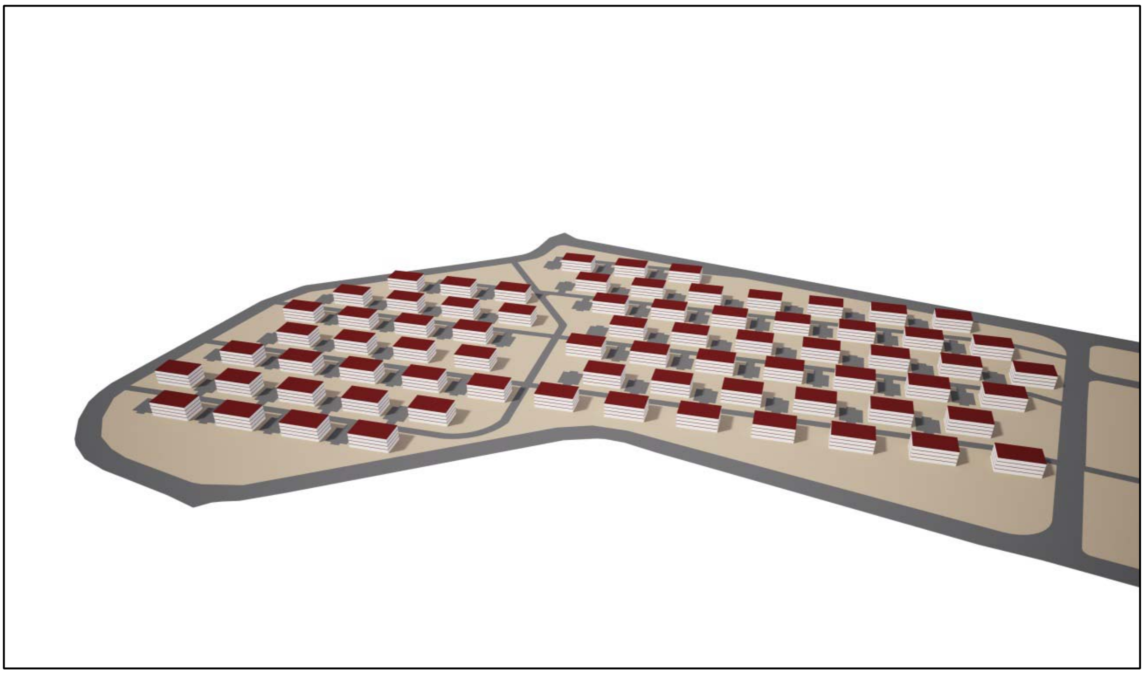


Figure 5.29. Site model of four-storey buildings alternative (Section 1).
(Source: Prepared on Autocad 2013 and Archicad 17 by Yelda Mert)

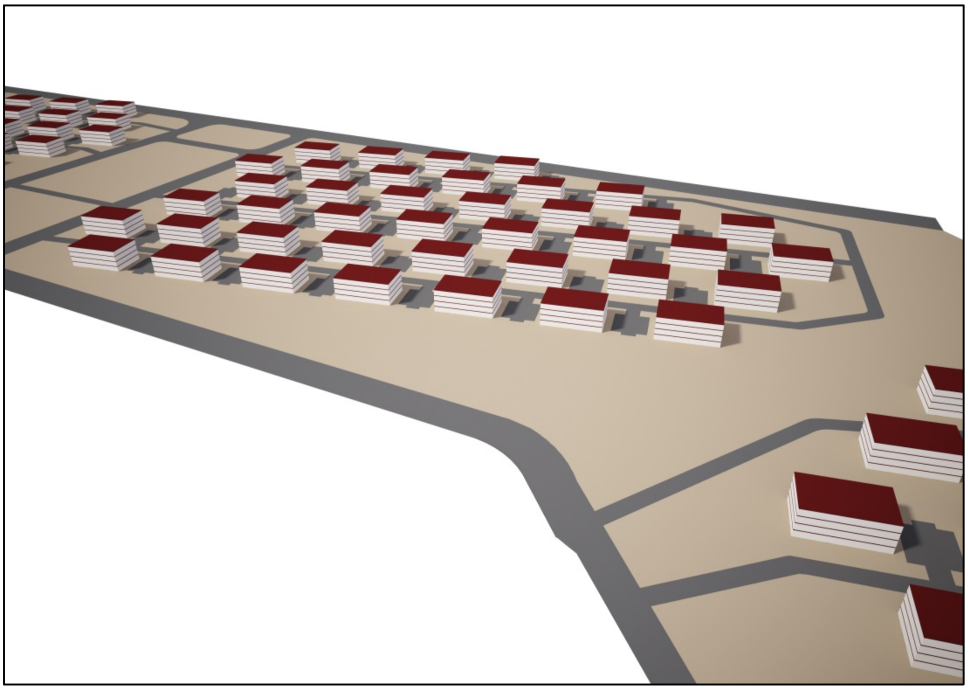


Figure 5.30. Site model of four-storey buildings alternative (Section 2).
(Source: Prepared on Autocad 2013 and Archicad 17 by Yelda Mert

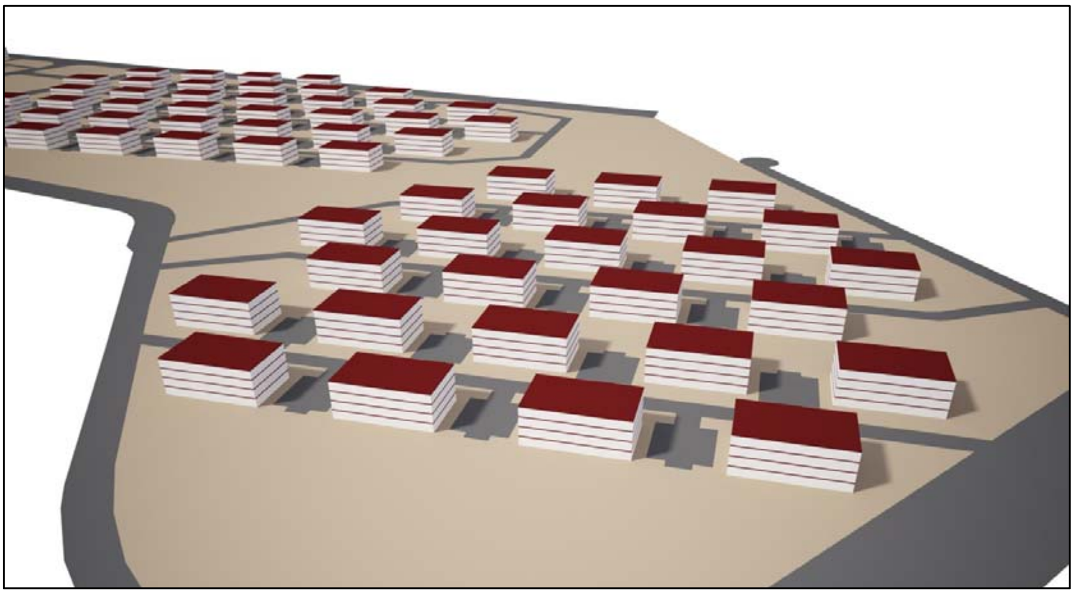


Figure 5.31. Site model of four-storey buildings alternative (Section 3).
(Source: Prepared on Autocad 2013 and Archicad 17 by Yelda Mert)

#### 5.3.9.2. Site Plan of Eight-Storey Building Block -Alternative B

In the eight-storey building block, there are 70 separate buildings each having 32 housing units with a total of 2240 units (Table 5.4). Green areas, playgrounds, sports area, parking area, social, cultural and educational areas are taken into consideration in the study. The detailed site plans of the eight-storey plans are shown in Figure 5.32, Figure 5.33, Figure 5.34, and Figure 5.35. Differing from the four-storey plan because of the increased heights of the buildings the distance between them is higher than the previous case. This causes a low number of buildings in the area but since the storey number is high total housing unit number is increased when four-storey plan is taken into consideration. The general and detailed 3D models of the eight-storey plan are shown in Figure 5.36, Figure 5.37, Figure5.37, Figure 5.38, and Figure 5.39. As is the four-storey plan, eight-storey plan also shows that, the distance between buildings and their orientation has a positive effect on the shadow effect. Again the shadows of the buildings are not blocking the other buildings solar gain.

Table 5.4. The details about the eight-storey plan.

| Storey | Number of Buildings | Number of Housing unit |
|---|---|---|
| **8** | 70 | 2240 |
| **Total** | **70** | **2240** |

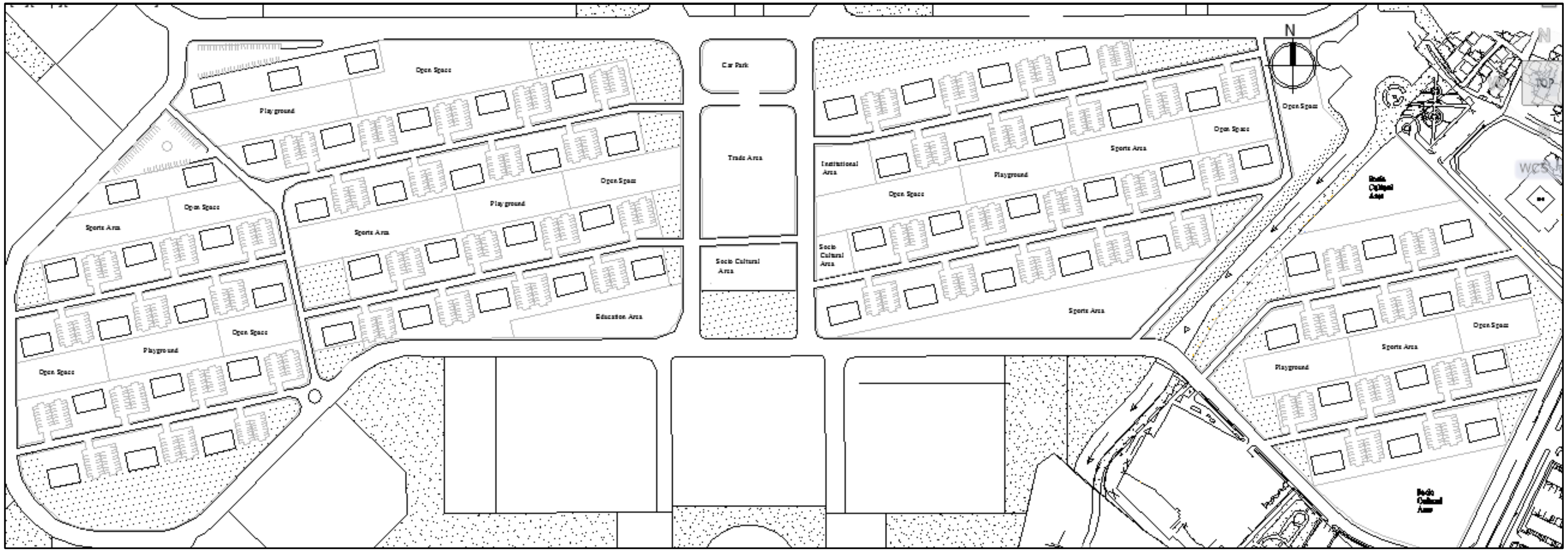



Figure 5.32. Site plan of eight-storey buildings alternative (Alternative B) (Prepared on Autocad 2013 by Yelda Mert).

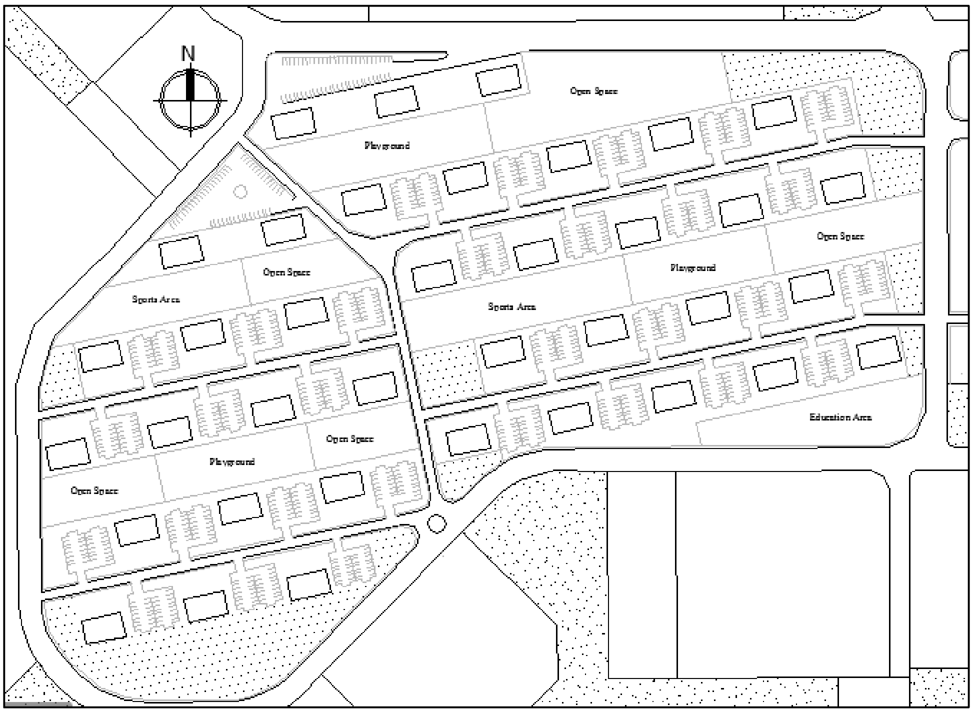



Figure 5.33. Site plan of eight-storey buildings alternative (Section 1).
(Source: Prepared on Autocad 2013 by Yelda Mert)

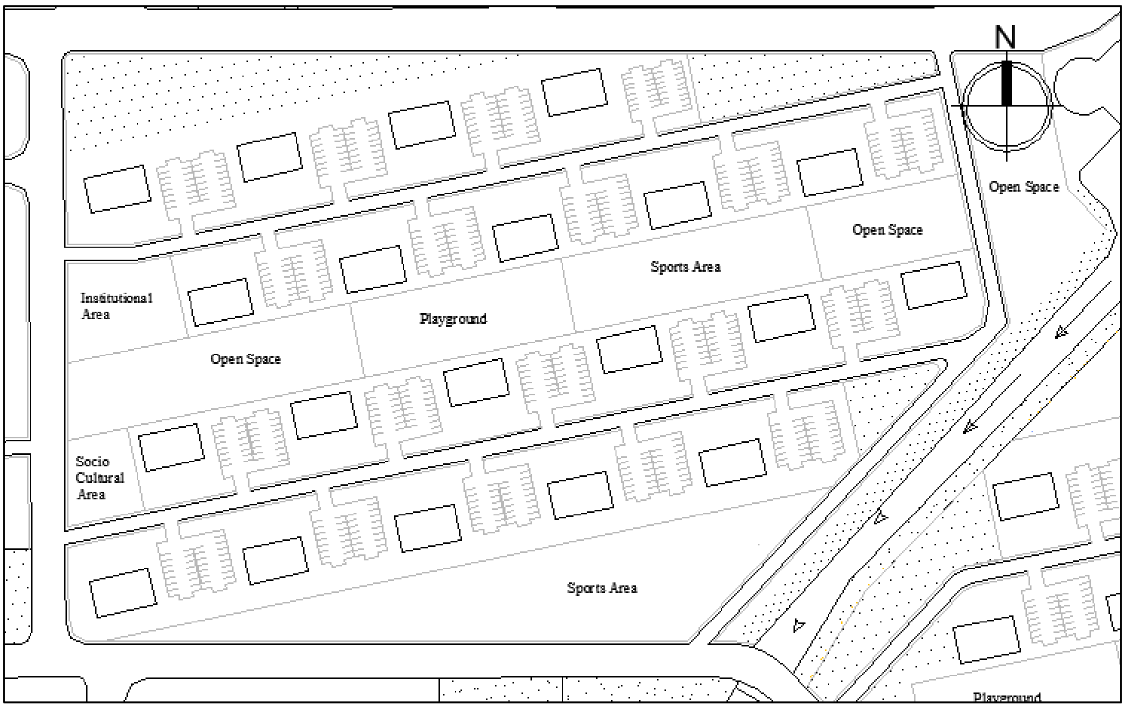



Figure 5.34. Site plan of eight-storey buildings alternative (Section 2).
(Source: Prepared on Autocad 2013 by Yelda Mert)

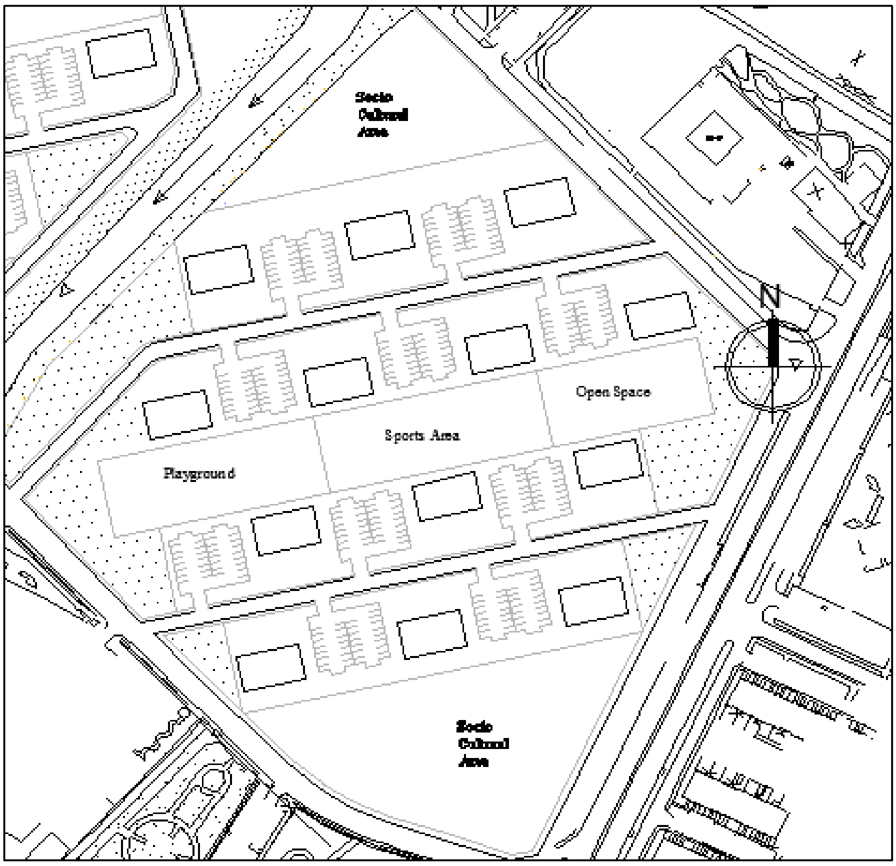



Figure 5.35. Site plan of eight-storey buildings alternative (Section 3).
(Source: Prepared on Autocad 2013 by Yelda Mert)

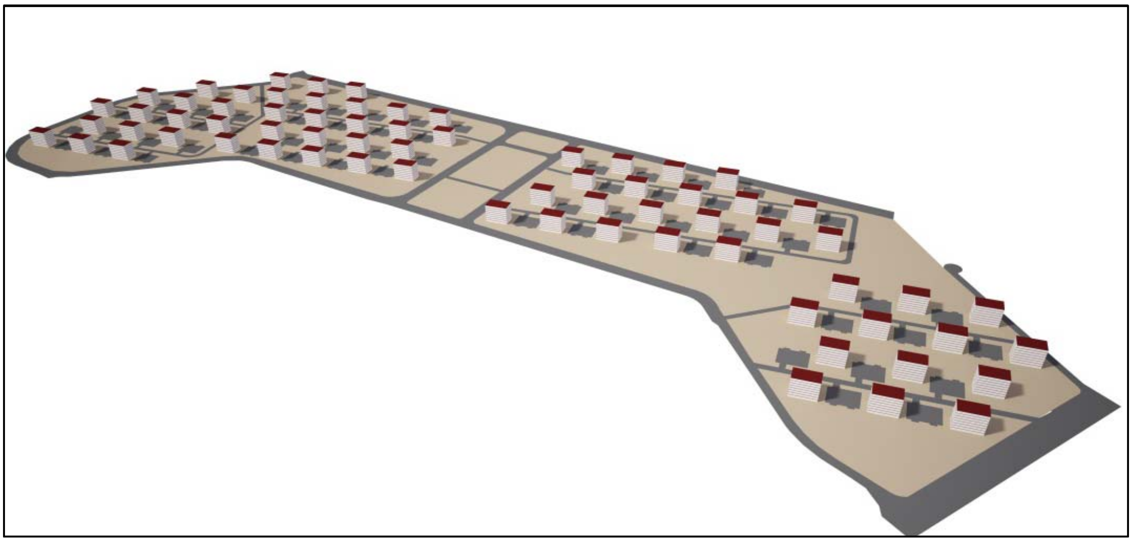


Figure 5.36. Site model of eight-storey buildings alternative.
(Source: Prepared on Autocad 2013 and Archicad 17 by Yelda Mert)

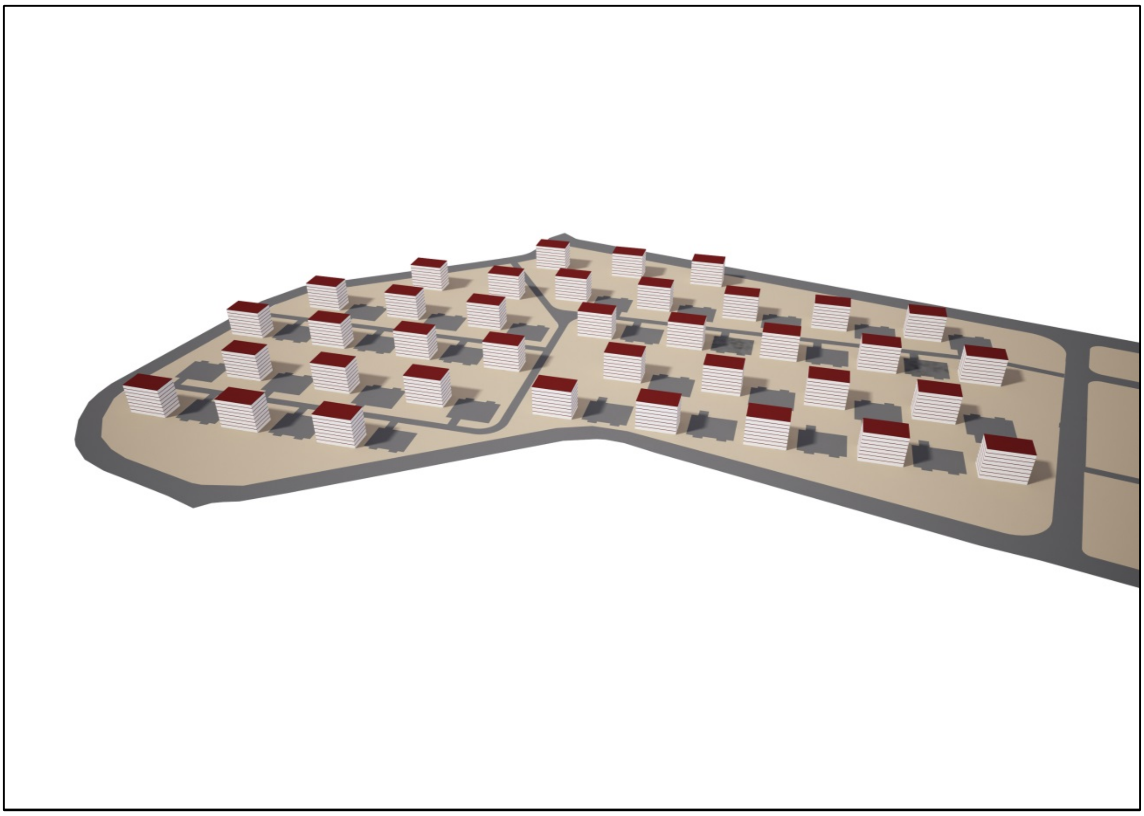


Figure 5.37. Site model of eight-storey buildings alternative (Section 1).
(Source: Prepared on Autocad 2013 and Archicad 17 by Yelda Mert)

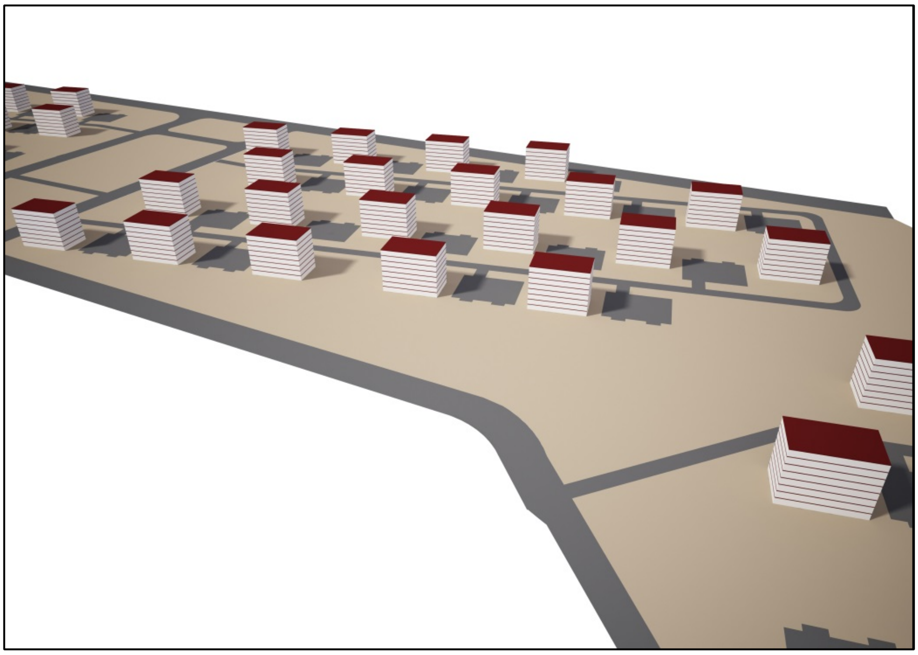


Figure 5.38. Site model of eight-storey buildings alternative (Section 2).
(Source: Prepared on Autocad 2013 and Archicad 17 by Yelda Mert)

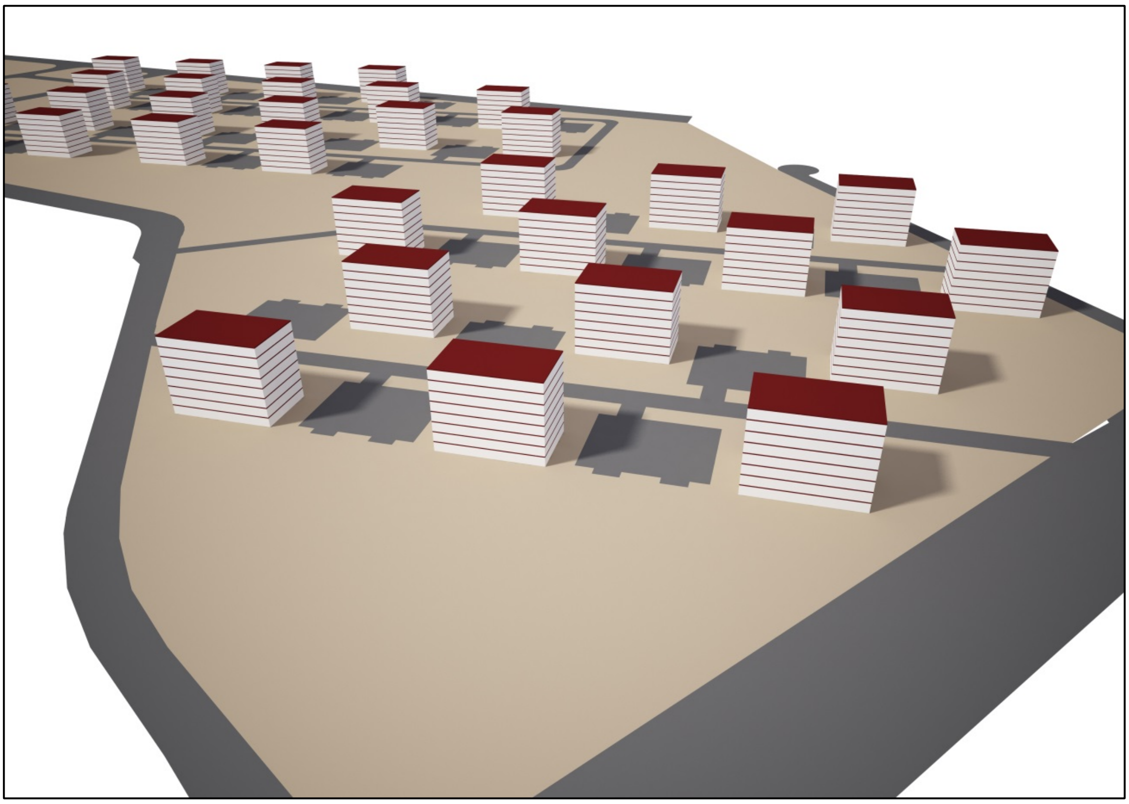


Figure 5.39. Site model of eight-storey buildings alternative (Section 3).
(Source: Prepared on Autocad 2013 and Archicad 17 by Yelda Mert)

### 5.3.9.3. Site Plan of Solar Envelope Based Design -Alternative C

In Figure 5.40 the site plan of the solar enveloped based design is shown. The storey number is changing from the range of 2 to 12. This selection is based on the peak point of the solar envelope and the prevailing angles of the solar envelop for east, west, north and south. Green areas, playgrounds, sports area, parking area, social, cultural and educational areas are taken into consideration in the study. Figure 5.41, Figure 5.42, and Figure 5.43 shows the site plan in details for building blocks. The effect of the solar envelop can be seen from these figures. The storey number of the buildings and height of the buildings are changing according to the solar envelope calculation. As a result of these the distance between the buildings are also effected and changing. In Table 5.5 the number of buildings and housing units in the proposed solar enveloped based design is shown.

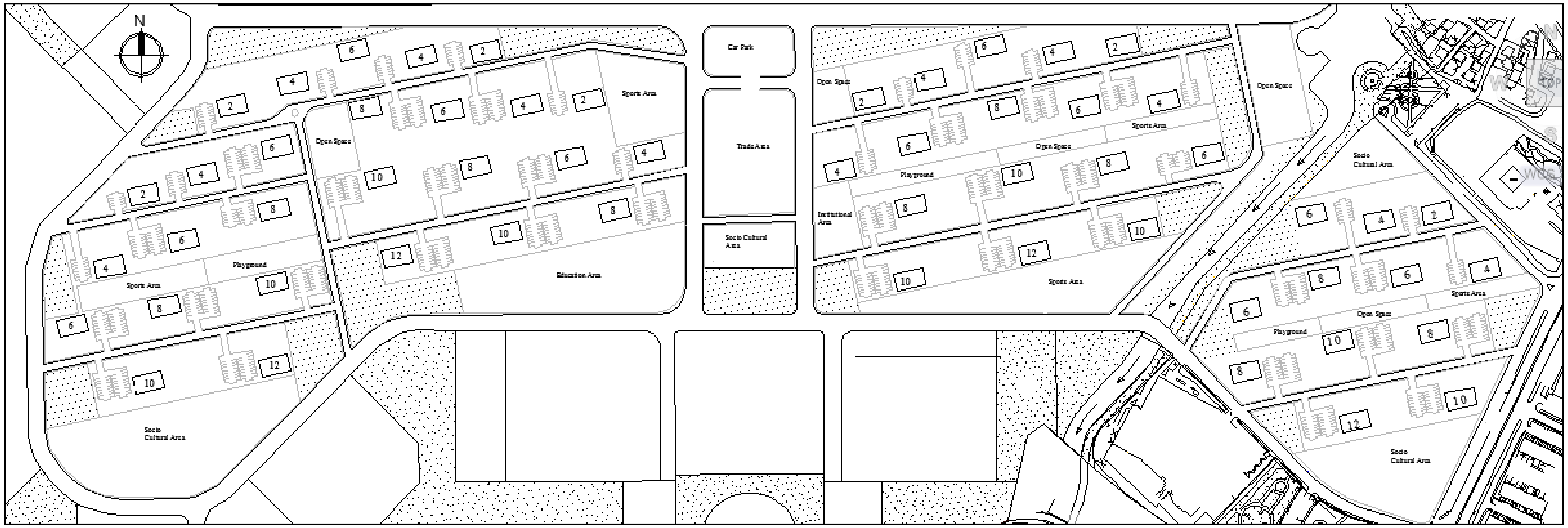


Figure 5.40. Site plan of solar envelope based alternative (Alternative C).
(Source: Prepared on Autocad 2013 by Yelda Mert)

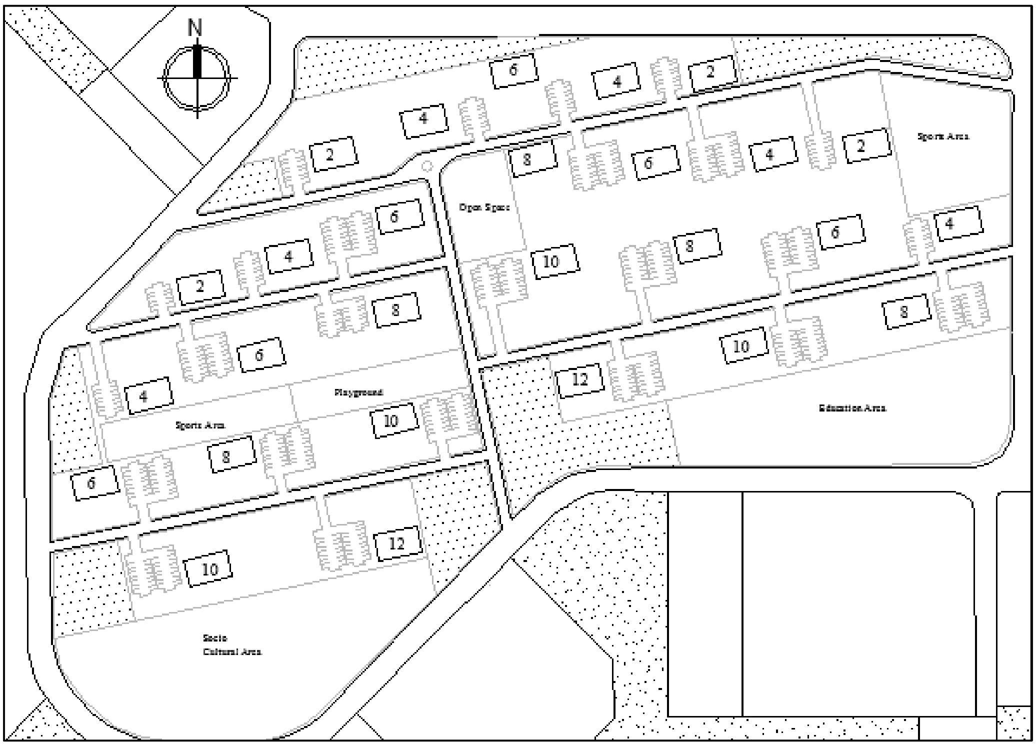



Figure 5.41. Site plan of solar envelope based alternative (Section 1).
(Source: Prepared on Autocad 2013 by Yelda Mert)

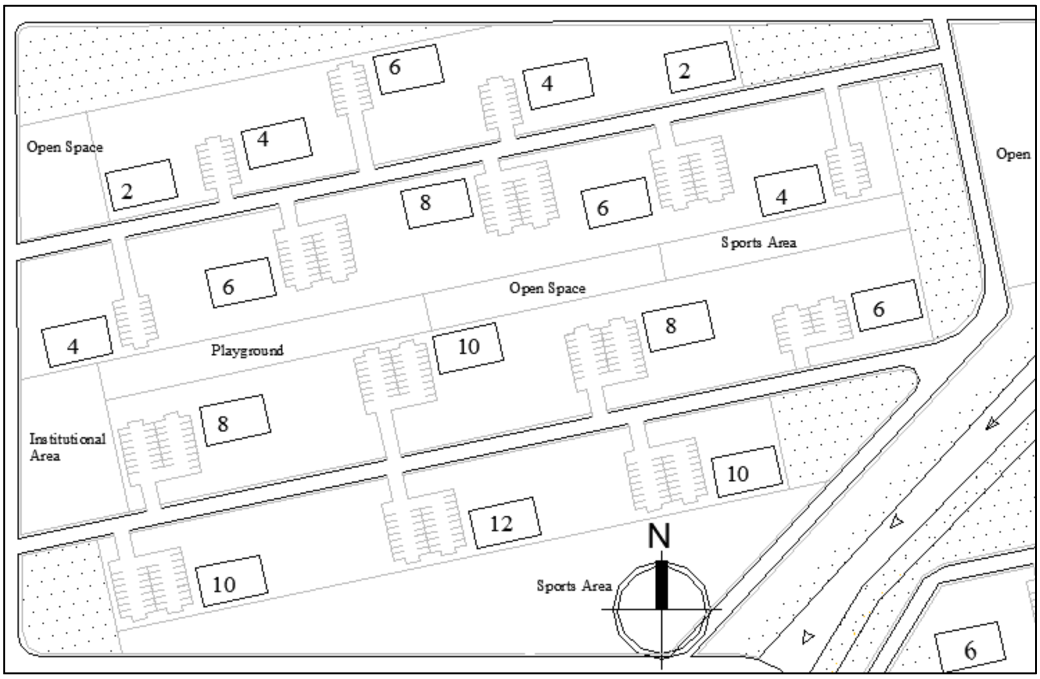



Figure 5.42. Site plan of solar envelope based alternative (Section 2).
(Source: Prepared on Autocad 2013 by Yelda Mert)

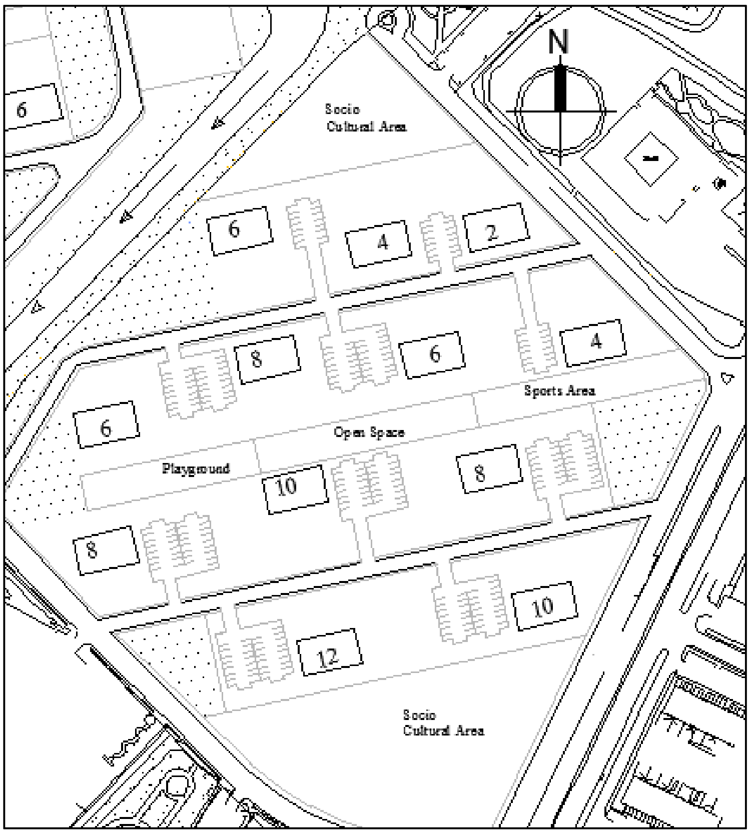



Figure 5.43. Site plan of solar envelope based alternative (Section 3).
(Source: Prepared on Autocad 2013 by Yelda Mert)

Table 5.5. The details about the solar enveloped based method.

| Storey | Number of Buildings | Number of Housing unit |
|---|---|---|
| **12** | 4 | 192 |
| **10** | 9 | 360 |
| **8** | 11 | 352 |
| **6** | 13 | 312 |
| **4** | 12 | 192 |
| **2** | 7 | 56 |
| **Total** | **56** | **1464** |

In addition to the plans, 3-D models are also developed for the solar envelope based design and the illustrations are shown in Figure 5.44, Figure 5.45, Figure 5.46, and Figure 5.47. The enveloped structure can be seen from these figures and the dynamic design can be evaluated. Besides, the minimum SEF can also be observed.

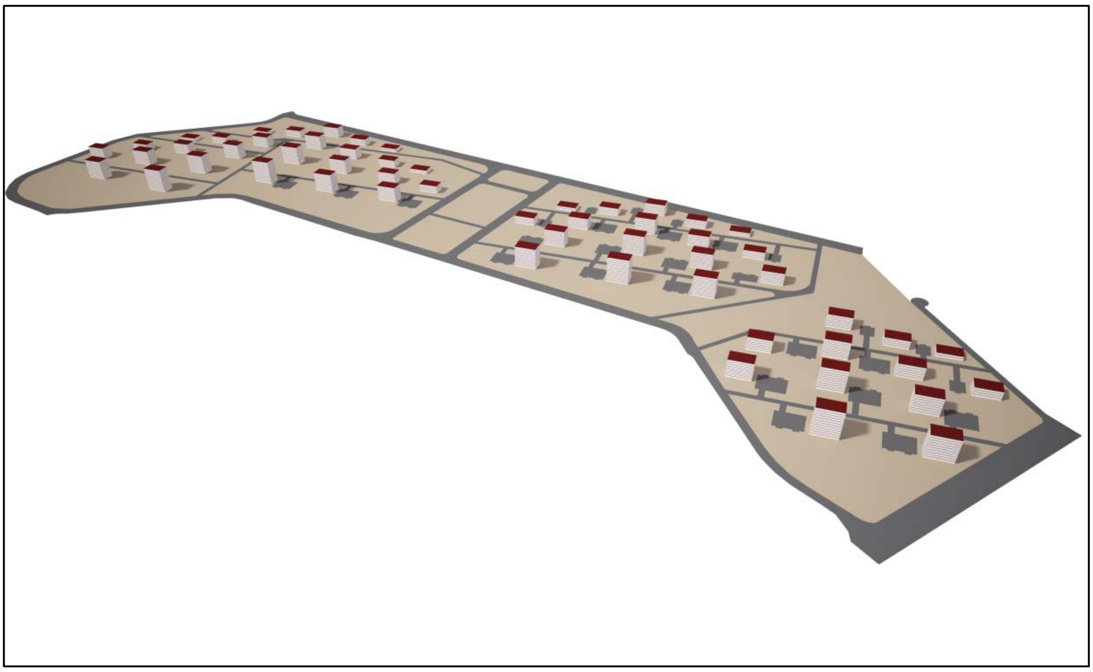


Figure 5.44. Site model of solar envelope based alternative.
(Source: Prepared on Autocad 2013 and Archicad 17 by Yelda Mert)

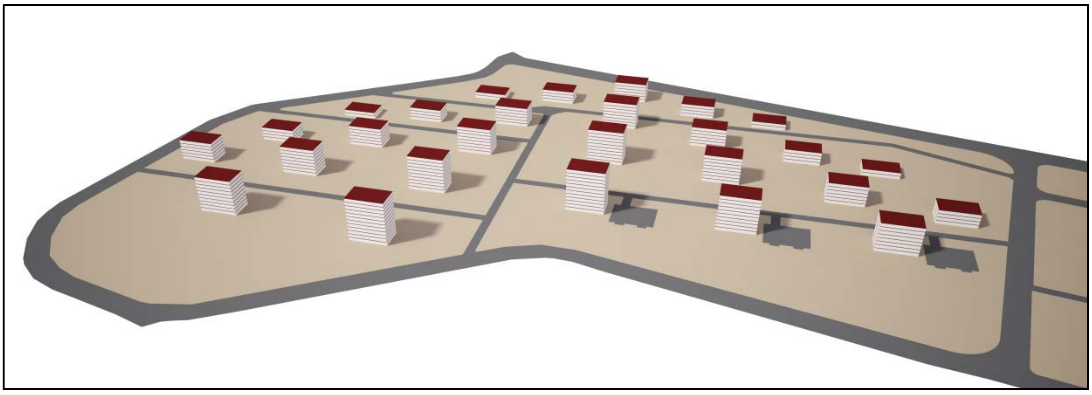


Figure 5.45. Site model of solar envelope based alternative (Section 1).
(Source: Prepared on Autocad 2013 and Archicad 17 by Yelda Mert)

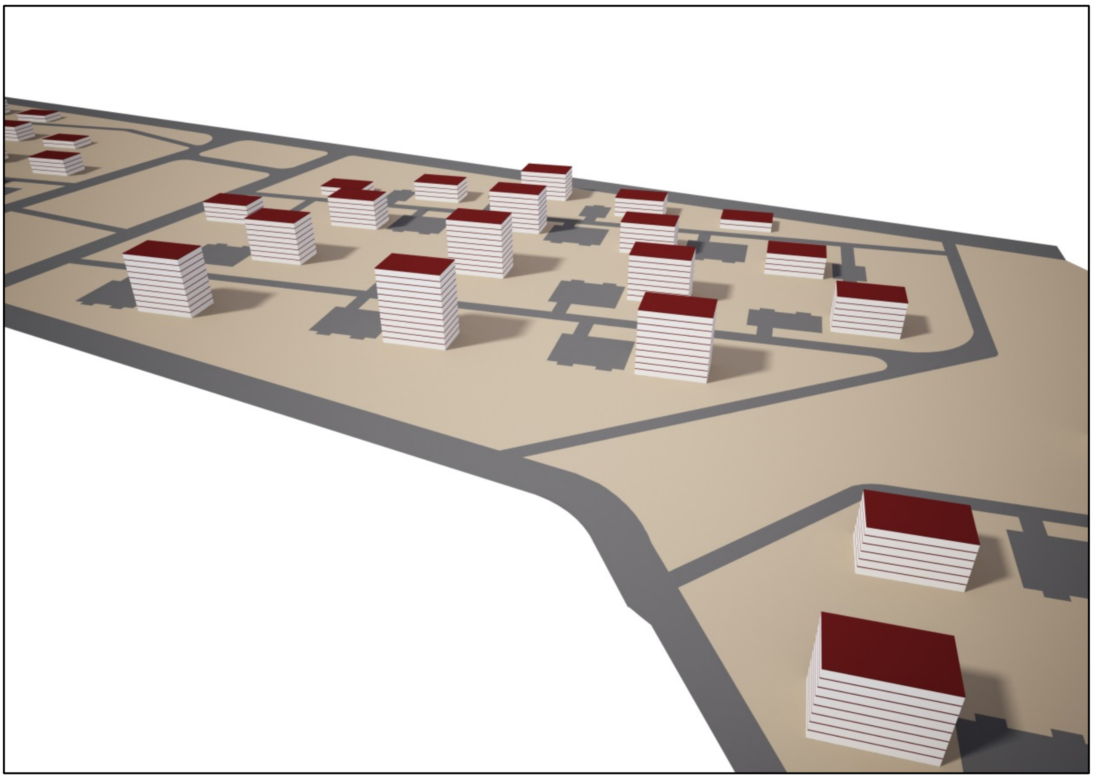


Figure 5.46. Site model of solar envelope based alternative (Section 2).
(Source: Prepared on Autocad 2013 and Archicad 17 by Yelda Mert)

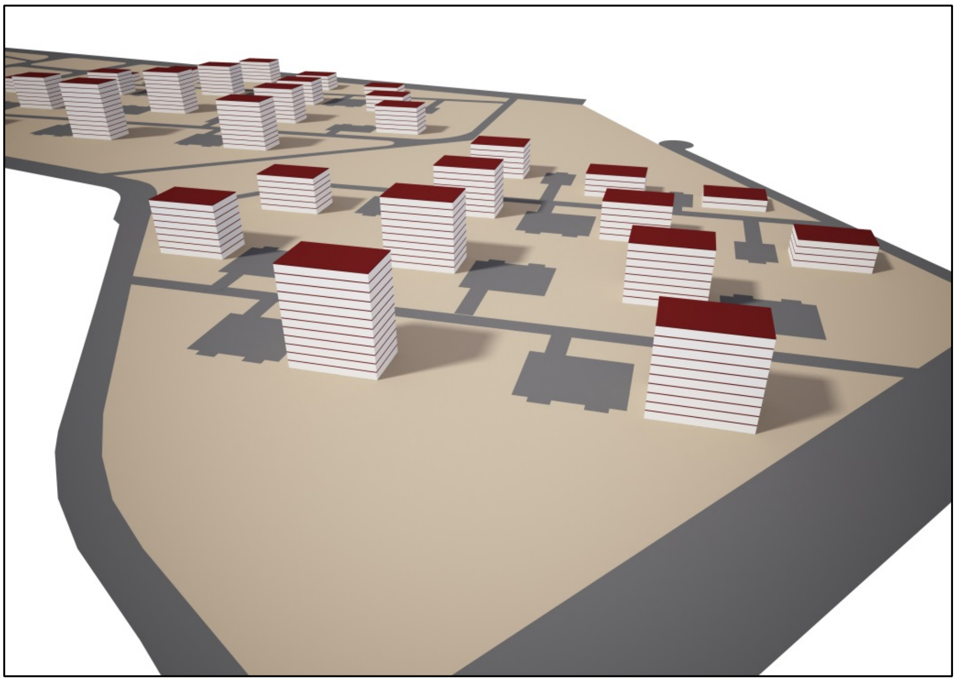


Figure 5.47. Site model of solar envelope based alternative (Section3).
(Source: Prepared on Autocad 2013 and Archicad 17 by Yelda Mert)

## 5.4. Results and Discussion

The findings of the study are presented and discussed also interpretation in this chapter in two subsections. The first subsection presents and discusses the exergy analysis results of the existing situation, and then in second subsection the results for the proposed plans are presented and discussed. Finally, the existing and proposed alternatives are compared and discussed.

### 5.4.1. Exergy Analysis of Existing Mavişehir Building Block Area: Mavişehir I, II

The algorithm described in Chapter 0 is used for evaluating the exergy analysis on the selected case area. In the calculations, the first and second stages of Mavişehir area are examined. The aim of the calculations is to reach the exergy loads of the buildings and exergy efficiencies as well as the exergy flexibility factor. In order to reach these values first the spatial, climatic and constructional properties of the buildings are gathered.

In the calculation of the exergy loads the insulation properties, passive heating with solar energy properties, openings and orientation properties and total facades of each building are taken into account. The exergy load of the buildings defines the amount of exergy needed by the building. This includes the passive solar effects and the effects of the surrounding. On the other hand, the exergy by fuel is the definition for the amount of fuel exergy must be supplied to the building.

The heat loss from the buildings happens in five different ways: through walls, windows, doors, roofs, floors to the ground.

Some assumptions made in the analysis are listed below:

- The reference state for exergy analysis is selected as 298 K temperature and 1 atm pressure in atmospheric concentrations.
- Indoor air temperature of 21° C .
- Outdoor temperature is 10.9° C as the average winter temperature of Izmir (between the years of 1960-2012) (MGM 2013)

- Outdoor temperature is 28.6 °C as the average summer temperature of Izmir (MGM 2013)
- The heat transfer coefficients of the walls and doors are gathered from real values depending on the plan details of the buildings which are obtained from the Karşıyaka Municipality and on the reported data of the construction company (Karşıyaka Municipality 2012).
- An average value of 4 residents is assumed during the calculations.
- 70°/50° heating system (inlet/outlet temperature of the radiators) is used in calculations in accordance with the reality and the condensing boiler systems.

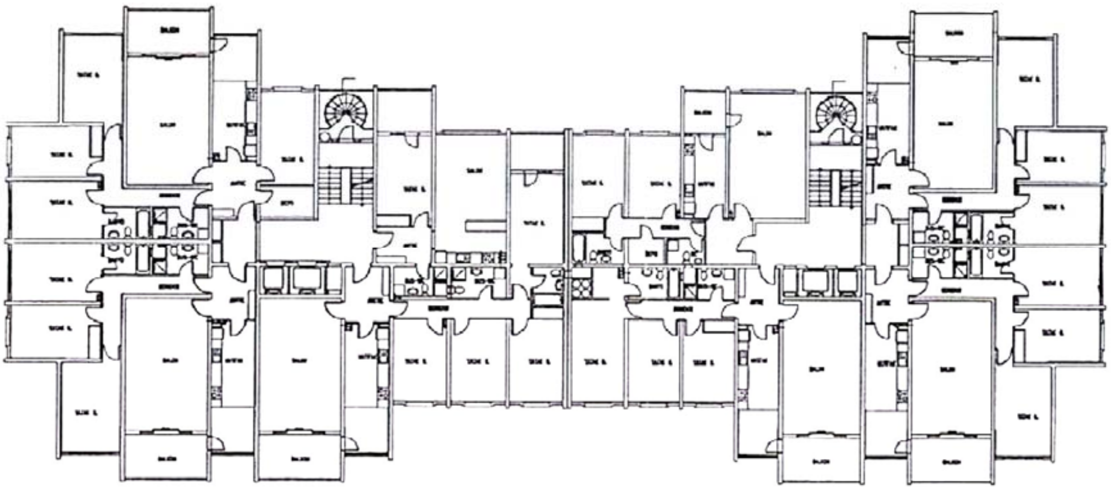


Figure 5.48. Plan of Pamukkale block.
(Source: Karşıyaka Municipality 2012)

In order to calculate heat loss the amounts of surfaces arising from the facades, roof and floors to ground are measured, calculated and tabulated in Table 5.6. These values are measured from the plan details of each type of building block. A sample plan of a building is shown in Figure 5.48.

Following the heat loss from the surfaces of buildings, heat gain by the solar energy must also be calculated. To reach this aim, the surfaces of the buildings are evaluated from the orientation point of view and tabulated in Table 5.7. One can see the Shadow Effect Factor (SEF) which is described previously and that indicates the ratio of the shaded time of the building to the daytime where there is no shadow.

Table 5.6. The data for the surface area of the buildings.
(Source: Calculated from the data of Karşıyaka Municipality 2012)

| **Building** | **Exterior Wall [m$^2$]** | **Window [m$^2$]** | **Door [m$^2$]** | **Roof [m$^2$]** | **Floors to ground [m$^2$]** |
|---|---|---|---|---|---|
| Albatros | 7832 | 822 | 602 | 667 | 667 |
| Flamingo | 4235 | 504 | 726 | 594 | 594 |
| Kuğu | 10003 | 1306 | 1309 | 1044 | 1044 |
| Kırlangıç | 18554 | 2378 | 1584 | 2793 | 2793 |
| Turna | 18554 | 2378 | 1584 | 2793 | 2793 |
| Selçuk | 7239 | 1463 | 1178 | 1312 | 1312 |
| Pamukkale | 7239 | 1463 | 1178 | 1312 | 1312 |
| Villa Selçuk | 1493 | 135.72 | 109.68 | 1200 | 1200 |
| Villa Pamukkale | 1493 | 135.72 | 109.68 | 1200 | 1200 |

For the calculation of the Shadow Effect Factors, 3-D models are developed and the previews for the summer and winter periods at selected times are generated. Moreover, a daily animation is created separately for each group of blocks and the Shadow Effect Factors are determined according to these visuals as it is seen in Figure 5.49, Figure 5.50, Figure 5.51, and Figure 5.52.

Determination of the facades of the buildings is very important in order to make the passive solar effect. It shows the effect of the orientation on the energy and exergy performance of the buildings. Every building in the area is evaluated separately and the facades that face southwest to southeast and northwest to northeast are calculated and taken into consideration.

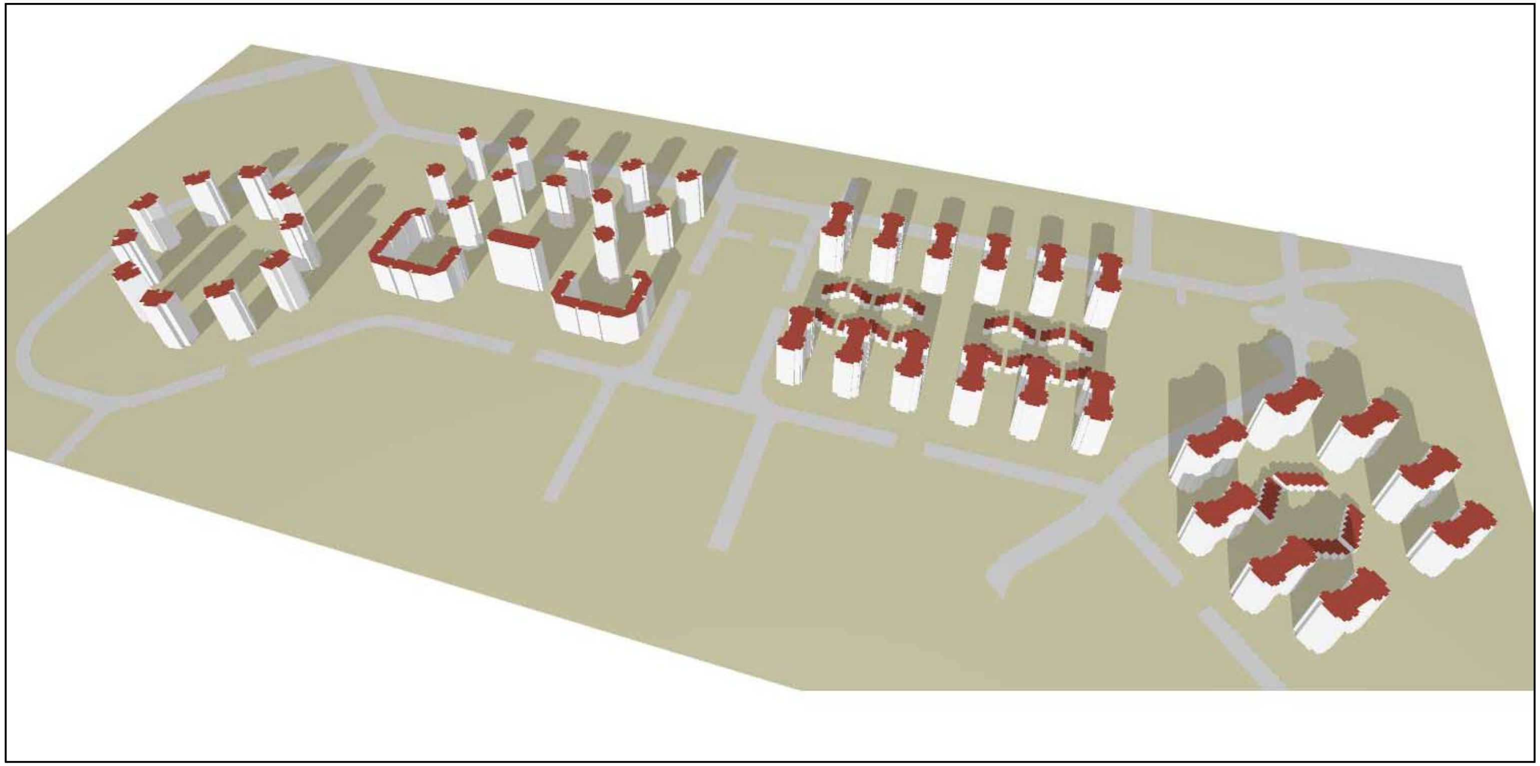


Figure 5.49. Site model of Mavişehir I-II at 21th December.
(Source: Prepared on Autocad 2013 and Archicad 17 by Yelda Mert)

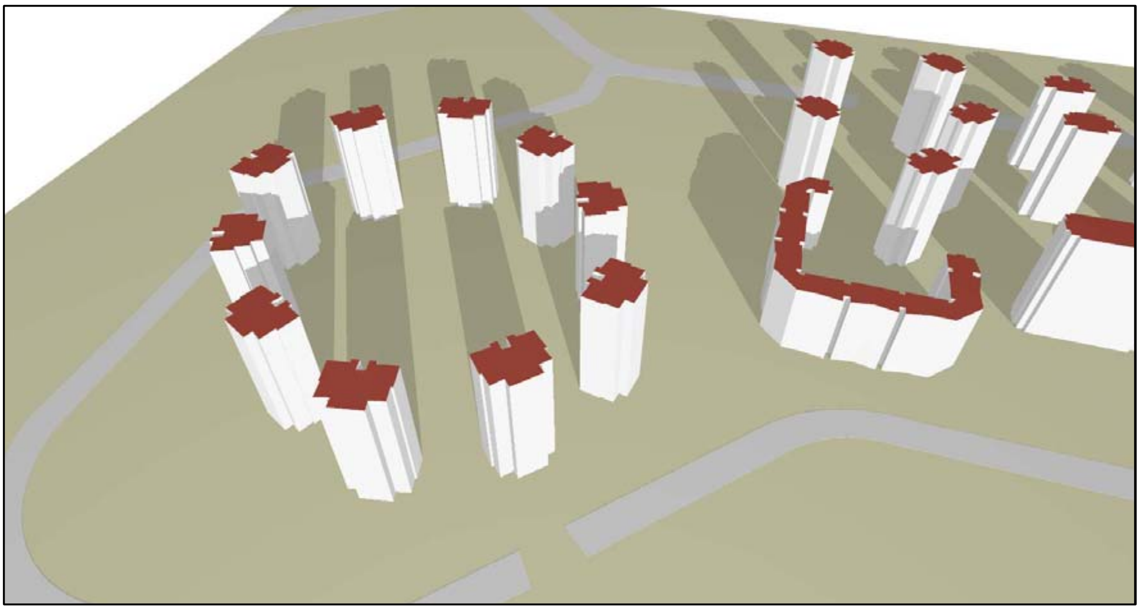


Figure 5.50. Site model of Mavişehir I-II at21th December.
(Source: The model is prepared on Autocad 2013 and Archicad 17 by Yelda Mert)

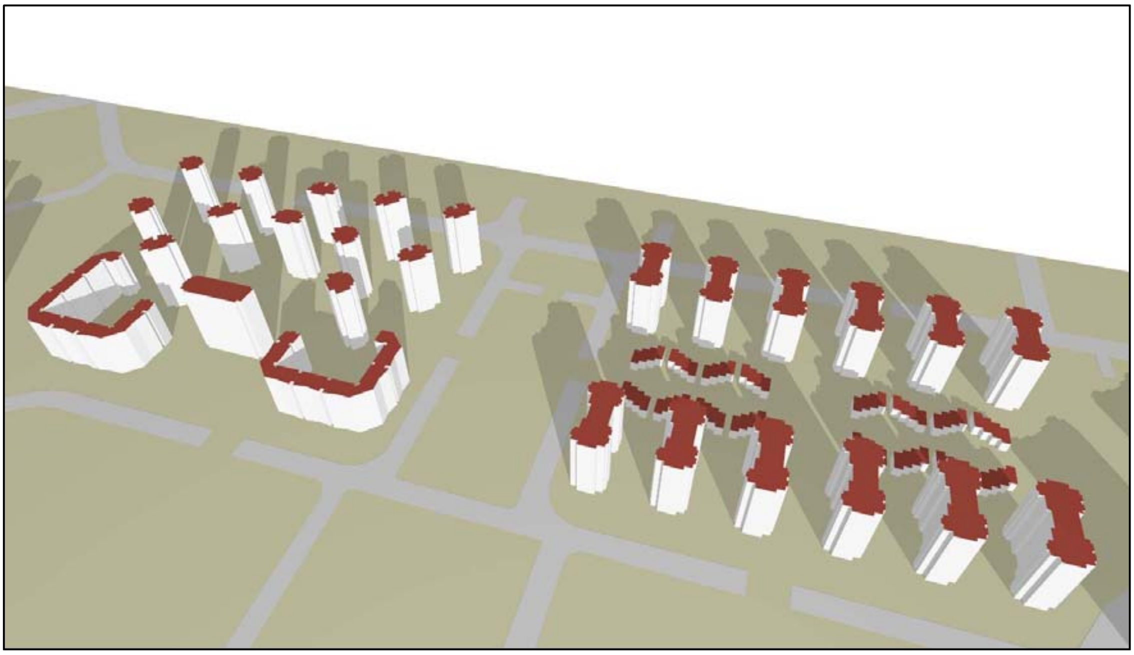


Figure 5.51. Site model of Mavişehir I-II at21th December.
(Source: The model is prepared on Autocad 2013 and Archicad 17 by Yelda Mert)

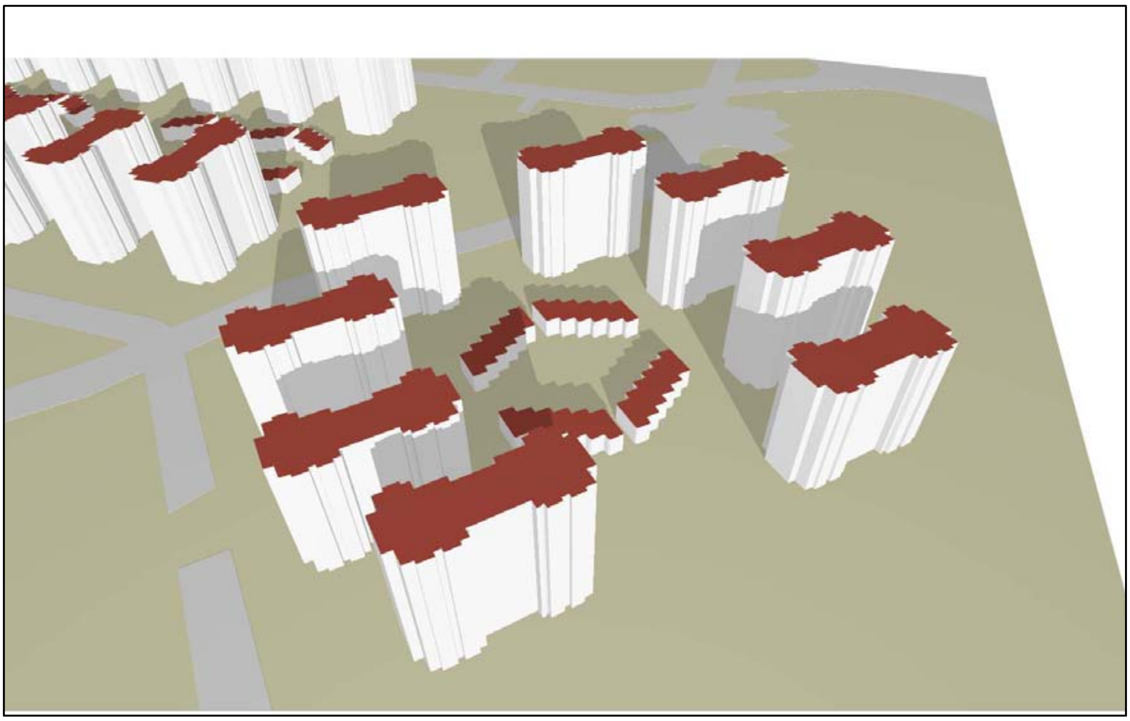


Figure 5.52. Site model of Mavişehir I-II at21$^{th}$ December.
(Source: The model is prepared on Autocad 2013 and Archicad 17 by Yelda Mert)

The results of the exergy analysis are demonstrated in Table 5.8. It is seen that the efficiency values are around 1.5-2% which is an expected value according to the literature (Hepbaşlı 2012). This is since a natural gas-fired heater is used for a domestic heating system and when the factors of heat transmission, heat loss and exergy destruction in the combustion process are taken into consideration. These values, in accordance with the literature are expected (Schmidt 2012) since they are considerably inefficient and energy consuming. It is seen that the small efficiency arise more from the buildings with bad orientation and SEF values as well as heat loss and inefficient equipment. Moreover, the exergy loads of those buildings are considerably higher than the better oriented and low SEF valued buildings. The abbreviations used in the table are illustrated in the Figure 5.53.

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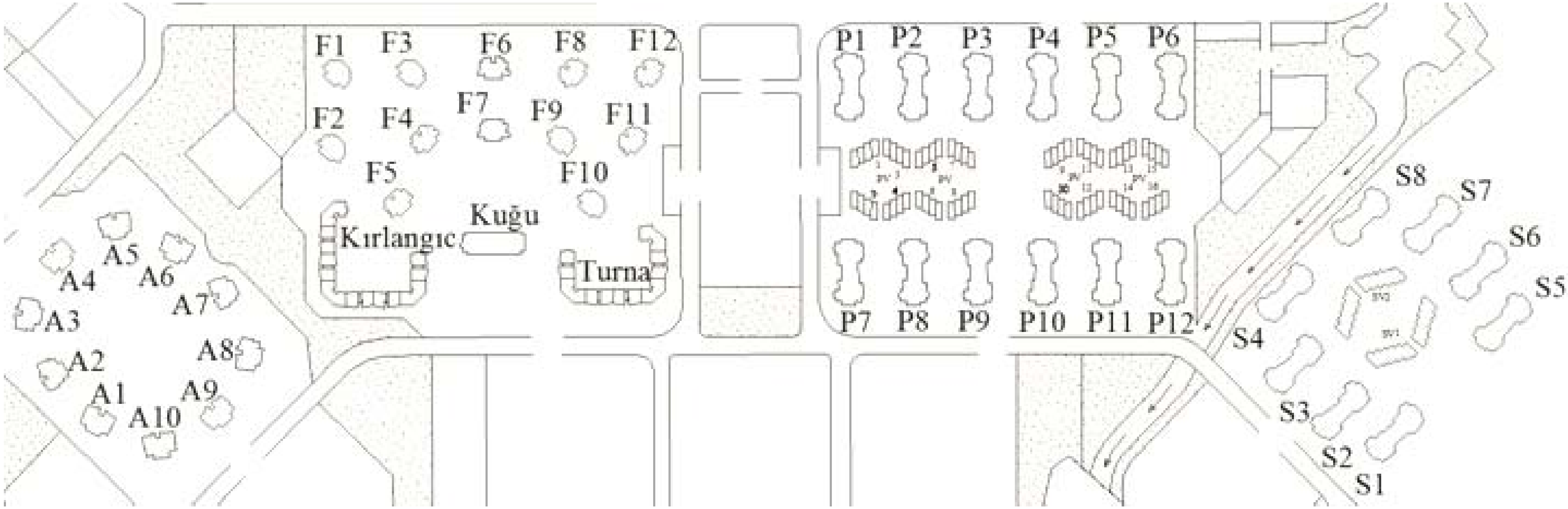


Figure 5.53. Abbreviations of buildings used in calculations.
(Source: Karşıyaka Municipality 2012)

Table 5.7. Data for SEF and the lateral areas with respect to the orientation.

| Building | South area [m$^2$] | North area [m$^2$] | Other area [m$^2$] | SEF [-] |
|---|---|---|---|---|
| A1 | 285.8 | 358.3 | 178.6 | 0 |
| A2 | 285.8 | 358.3 | 821.7 | 5 |
| A3 | 408.1 | 250.1 | 57.4 | 8 |
| A4 | 321.6 | 214.4 | 286.9 | 30 |
| A5 | 357.3 | 465.5 | 0.0 | 30 |
| A6 | 285.8 | 429.8 | 107.2 | 8 |
| A7 | 285.8 | 358.3 | 821.7 | 5 |
| A8 | 408.1 | 250.1 | 57.4 | 35 |
| A9 | 321.6 | 214.4 | 286.9 | 5 |
| A10 | 357.3 | 465.5 | 0.0 | 3 |
| F1 | 170.0 | 107.3 | 277.2 | 8 |
| F2 | 154.5 | 97.5 | 252.0 | 8 |
| F3 | 170.0 | 107.3 | 277.2 | 10 |
| F4 | 170.0 | 107.3 | 277.2 | 10 |
| F5 | 170.0 | 107.3 | 277.2 | 5 |
| F6 | 192.0 | 78.0 | 234.0 | 20 |
| F7 | 211.2 | 85.8 | 257.4 | 8 |
| F8 | 170.0 | 107.3 | 277.2 | 10 |
| F9 | 170.0 | 107.3 | 277.2 | 8 |
| F10 | 170.0 | 107.3 | 277.2 | 5 |
| F11 | 154.5 | 97.5 | 252.0 | 5 |
| F12 | 170.0 | 107.3 | 277.2 | 3 |
| Kırlangıç | 1062.3 | 548.0 | 768.6 | 3 |
| Turna | 938.0 | 117.4 | 577.9 | 3 |
| Kuğu | 407.9 | 407.9 | 491.0 | 3 |
| P1 | 862.4 | 862.4 | 1267.2 | 3 |
| P2 | 862.4 | 862.4 | 1267.2 | 3 |
| P3 | 862.4 | 862.4 | 1267.2 | 5 |
| P4 | 862.4 | 862.4 | 1267.2 | 5 |
| P5 | 862.4 | 862.4 | 1267.2 | 5 |
| P6 | 862.4 | 862.4 | 1267.2 | 5 |
| P7 | 862.4 | 862.4 | 1267.2 | 0 |
| P8 | 862.4 | 862.4 | 1267.2 | 3 |
| P9 | 862.4 | 862.4 | 1267.2 | 3 |
| P10 | 862.4 | 862.4 | 1267.2 | 3 |
| P11 | 862.4 | 862.4 | 1267.2 | 3 |
| P12 | 862.4 | 862.4 | 1267.2 | 3 |
| PV1 | 61 | 61 | 0 | 50 |
| PV2 | 61 | 61 | 0 | 50 |
| PV3 | 61 | 61 | 0 | 70 |
| PV4 | 61 | 61 | 0 | 80 |
| PV5 | 61 | 61 | 0 | 80 |

**(cont. on next page)**

Table 5.7. (cont.).

| Building | South area [$m^2$] | North area [$m^2$] | Other area [$m^2$] | SEF [-] |
|---|---|---|---|---|
| PV6 | 61 | 61 | 0 | 80 |
| PV7 | 61 | 61 | 0 | 75 |
| PV8 | 61 | 61 | 0 | 70 |
| PV9 | 61 | 61 | 0 | 60 |
| PV10 | 61 | 61 | 0 | 60 |
| PV11 | 61 | 61 | 0 | 75 |
| PV12 | 61 | 61 | 0 | 80 |
| PV13 | 61 | 61 | 0 | 80 |
| PV14 | 61 | 61 | 0 | 80 |
| PV15 | 61 | 61 | 0 | 70 |
| PV16 | 61 | 61 | 0 | 60 |
| S1 | 665 | 665 | 1292 | 0 |
| S2 | 665 | 665 | 1292 | 10 |
| S3 | 665 | 665 | 1292 | 30 |
| S4 | 665 | 665 | 1292 | 20 |
| S5 | 665 | 665 | 1292 | 0 |
| S6 | 665 | 665 | 1292 | 10 |
| S7 | 665 | 665 | 1292 | 30 |
| S8 | 665 | 665 | 1292 | 20 |
| SV1 | 20 | 13 | 33 | 50 |
| SV2 | 20 | 13 | 33 | 60 |

On the other hand, the exergy loads for summer (Table 5.8) mostly arise from the cooling loads in the area due to the high temperature in the case area. It is also seen that the cooling loads are much higher than the heating loads. Besides cooling loads are also effected from the SEF since the increased heat gain increases the cooling load in buildings. It is clearly seen in the Selcuk buildings that Selcuk-3 has the lowest cooling load value since the shadow effect is at the highest value of 30. That leads us to investigate the importance of insulation and orientation in both summer and winter seasons.

The exergy flexibility factors (Table 5.8) of the building block are around 11-15% that is the ratio of the exergy demand to the exergy input. This indicates that any replacement in the system will clearly increase the efficiency and support effective and renewable energy systems such as usage of solar power, fuel cells or wind energy.

Table 5.8. Results for the exergy analysis.

| Building | Exergy Load Summer [kW] | Exergy Load Winter [kW] | Exergy by Fuel [kW] | Exergy Efficiency [%] | Exergy Flexibility Factor [%] |
|---|---|---|---|---|---|
| A1 | 314.50 | 195.58 | 131.70 | 1.8285 | 13.792 |
| A2 | 314.10 | 195.73 | 131.81 | 1.8289 | 13.795 |
| A3 | 313.75 | 195.86 | 131.91 | 1.8292 | 13.797 |
| A4 | 312.99 | 196.14 | 132.12 | 1.8300 | 13.803 |
| A5 | 312.99 | 196.63 | 132.50 | 1.8312 | 13.812 |
| A6 | 313.75 | 195.97 | 131.99 | 1.8295 | 13.800 |
| A7 | 314.10 | 191.70 | 128.72 | 1.8185 | 13.716 |
| A8 | 310.62 | 197.01 | 132.79 | 1.8322 | 13.819 |
| A9 | 314.10 | 195.30 | 131.48 | 1.8278 | 13.787 |
| A10 | 314.40 | 195.62 | 131.72 | 1.8286 | 13.793 |
| F1 | 212.33 | 129.33 | 82.92 | 1.6558 | 12.489 |
| F2 | 212.33 | 117.99 | 75.63 | 1.6549 | 12.482 |
| F3 | 211.98 | 129.19 | 82.81 | 1.6551 | 12.484 |
| F4 | 211.98 | 129.19 | 82.81 | 1.6551 | 12.484 |
| F5 | 212.22 | 129.10 | 82.75 | 1.6546 | 12.480 |
| F6 | 194.03 | 118.06 | 75.69 | 1.6553 | 12.485 |
| F7 | 212.33 | 117.46 | 75.22 | 1.6518 | 12.459 |
| F8 | 211.98 | 129.19 | 82.81 | 1.6551 | 12.484 |
| F9 | 212.33 | 129.15 | 82.79 | 1.6549 | 12.482 |
| F10 | 212.22 | 129.10 | 82.75 | 1.6546 | 12.480 |
| F11 | 212.22 | 114.16 | 72.70 | 1.6323 | 12.312 |
| F12 | 212.32 | 129.07 | 82.72 | 1.6544 | 12.479 |
| Kırlangıç | 765.07 | 379.89 | 284.67 | 2.2369 | 16.872 |
| Turna | 753.56 | 384.14 | 287.92 | 2.2378 | 16.879 |
| Kuğu | 426.71 | 190.93 | 130.92 | 1.8950 | 14.293 |
| P1 | 400.21 | 221.31 | 136.36 | 1.5209 | 11.472 |
| P2 | 400.21 | 218.91 | 136.17 | 1.5527 | 11.712 |
| P3 | 398.29 | 219.09 | 136.31 | 1.5534 | 11.717 |
| P4 | 398.29 | 219.09 | 136.31 | 1.5534 | 11.717 |
| P5 | 398.29 | 219.09 | 136.31 | 1.5534 | 11.717 |
| P6 | 398.29 | 221.49 | 136.50 | 1.5216 | 11.477 |
| P7 | 399.51 | 218.64 | 135.96 | 1.5518 | 11.705 |
| P8 | 400.21 | 218.91 | 136.17 | 1.5527 | 11.712 |
| P9 | 400.21 | 218.91 | 136.17 | 1.5527 | 11.712 |
| P10 | 400.21 | 218.91 | 136.17 | 1.5527 | 11.712 |
| P11 | 400.21 | 218.91 | 136.17 | 1.5527 | 11.712 |
| P12 | 400.21 | 218.91 | 136.17 | 1.5527 | 11.712 |
| PV1 | 83.23 | 44.47 | 30.84 | 1.9392 | 14.627 |

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Table 5.8. (cont.)

| Building | Exergy Load Summer [kW] | Exergy Load Winter [kW] | Exergy by Fuel [kW] | Exergy Efficiency [%] | Exergy Flexibility Factor [%] |
|---|---|---|---|---|---|
| PV2 | 83.23 | 44.47 | 30.84 | 1.9392 | 14.627 |
| PV3 | 82.88 | 44.59 | 30.94 | 1.9403 | 14.635 |
| PV4 | 82.71 | 44.66 | 30.99 | 1.9409 | 14.640 |
| PV5 | 82.71 | 44.66 | 30.99 | 1.9409 | 14.640 |
| PV6 | 82.71 | 44.66 | 30.99 | 1.9409 | 14.640 |
| PV7 | 82.79 | 44.63 | 30.96 | 1.9406 | 14.637 |
| PV8 | 82.88 | 44.59 | 30.94 | 1.9403 | 14.635 |
| PV9 | 83.05 | 44.53 | 30.89 | 1.9398 | 14.631 |
| PV10 | 83.05 | 44.53 | 30.89 | 1.9398 | 14.631 |
| PV11 | 82.79 | 44.63 | 30.96 | 1.9406 | 14.637 |
| PV12 | 82.71 | 44.66 | 30.99 | 1.9409 | 14.640 |
| PV13 | 82.71 | 44.66 | 30.99 | 1.9409 | 14.640 |
| PV14 | 82.71 | 44.66 | 30.99 | 1.9409 | 14.640 |
| PV15 | 82.88 | 44.59 | 30.94 | 1.9403 | 14.635 |
| PV16 | 83.05 | 44.53 | 30.89 | 1.9398 | 14.631 |
| S1 | 393.55 | 223.77 | 138.24 | 1.5298 | 11.539 |
| S2 | 387.37 | 217.25 | 138.21 | 1.6288 | 12.285 |
| S3 | 383.60 | 218.64 | 139.28 | 1.6332 | 12.319 |
| S4 | 389.78 | 225.16 | 139.31 | 1.5347 | 11.576 |
| S5 | 393.55 | 216.55 | 137.68 | 1.6265 | 12.268 |
| S6 | 387.37 | 224.47 | 138.78 | 1.5322 | 11.557 |
| S7 | 383.60 | 225.86 | 139.84 | 1.5371 | 11.594 |
| S8 | 389.78 | 225.16 | 139.31 | 1.5347 | 11.576 |
| SV1 | 43.17 | 16.34 | 10.18 | 1.5633 | 11.791 |
| SV2 | 43.12 | 16.36 | 10.19 | 1.5643 | 11.799 |

Table 5.9 tabulates the total exergy load of the building block with the total efficiency and flexibility factors for summer and winter. It is seen that the exergy load value is very large and proves the estimations about the residential energy consumption. It is also seen that summer value nearly doubles the winter value. This leads us to conclude that the designers and city planners should understand and internalize the energy concerns while making decisions and developing designs. This is, keeping in mind that energy demand and cost will be the prevailing cost of the building and the increasing price and decreasing supply of the energy from fossil fuels.

Table 5.9. Exergy results of existing case of Mavişehir Area.

| | |
|---|---|
| **Exergy Load Winter [kW]** | 9567 |
| **Exergy Load Summer [kW]** | 16924 |
| **Exergy Efficiency [-]** | 1.7427 |
| **Exergy Flexibility Factor [-]** | 13.14 |

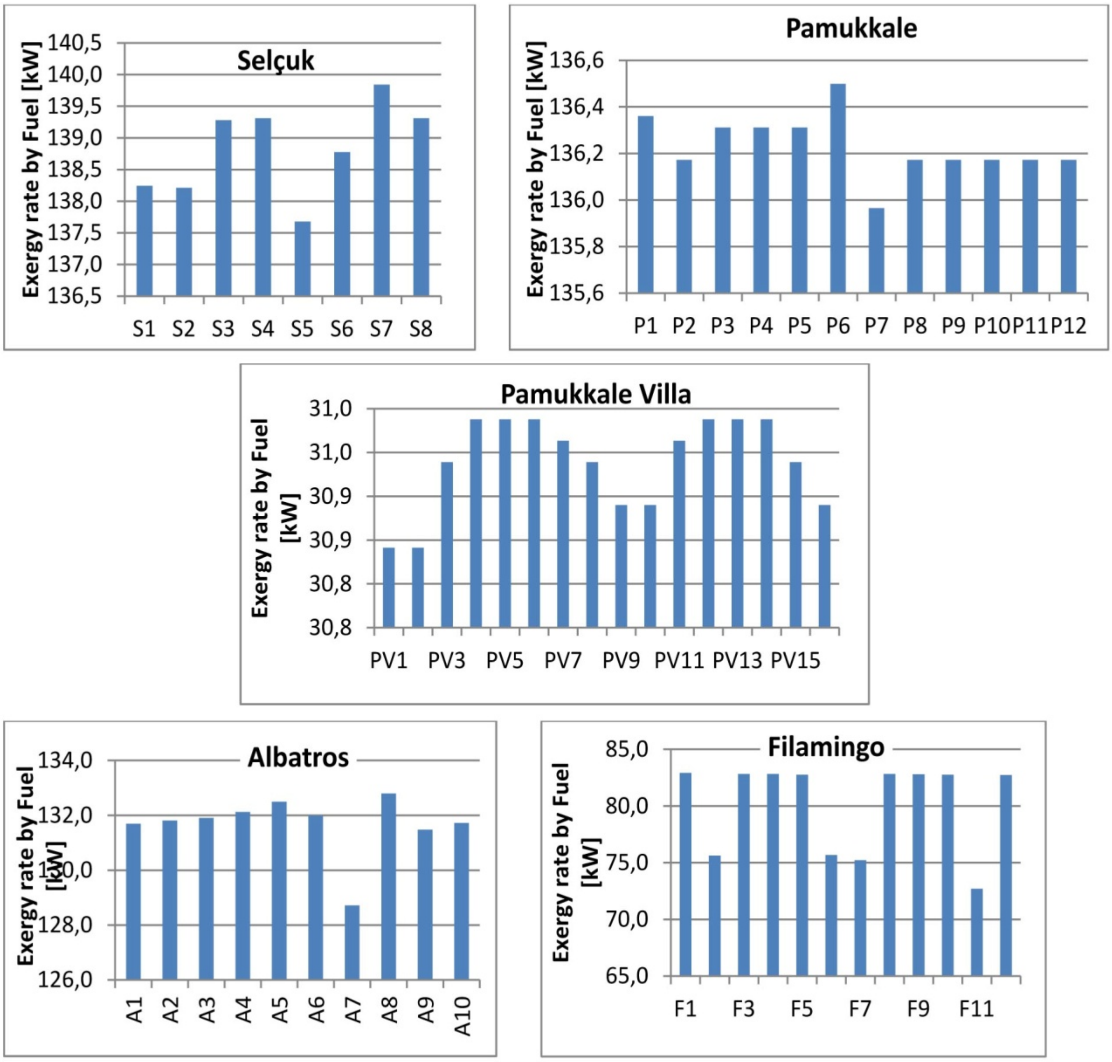


Figure 5.54. Exergy by fuel values of various buildings in the case-area.

The values for the exergy by fuel that is an indication of the amount of energy input to the area by means of fuel. This value is a tool for reaching the energy cost in the area (Figure 5.54). It is seen that for similar shaped buildings in same construction sites exergy by fuel values are changing. The main reason behind this situation mostly arises from the orientation and the SEF of the building. The main reason behind this situation mostly arises from the orientation and the SEF of the building. When the literature (Hepbaşlı 2012) values of exergy by fuel results are discussed it is seen that results are quite similar but in this study the effect of SEF is introduced that brings another perspective to the analysis. Besides the results of the SEF effect is also as expected since with increasing shadow effect factor the exergy by fuel values are incre4aes for each building block.

### 5.4.2. Exergy Analysis of Proposed Plan Alternatives

In this chapter the results of the proposed plans are presented and discussed for the case area Mavişehir I and Mavişehir II. Also the comparison between the plans is developed.

The results of the exergy analysis of the proposed plan alternatives are given for three different building plans for four-storey and eight-storey building blocks scheme in this section.

According to the proposed plans of the three building block scheme the necessary data are calculated and presented in the Table 5.10. For the calculation of the heat loss and heat gain through the doors and windows the surface areas are important. These data are used in the exergy calculation of the case area. The plan 3 has the least wall area and window-door area but the plan 2 has the largest surface areas that are effective for heat loss.

Table 5.10. The data for the surface area of the buildings in the proposed plan alternatives.

| **Building** | **Exterior wall [m$^2$]** | **Window-Door [m$^2$]** | **Roof [m$^2$]** | **Floors to ground [m$^2$]** |
|---|---|---|---|---|
| Plan 1 | 1002 | 173.6 | 522 | 522 |
| Plan 2 | 1210 | 181 | 540 | 540 |
| Plan 3 | 982 | 169 | 448 | 448 |

The general exergy analysis results for a single block of building is calculated for each plan and tabulated in Table 5.11. As it is seen the exergy values varies depending on the plan since the window, door, roof and wall areas differs depending on the plan. These are expected regarding the heat loss and heat gain with surroundings and it gives us the chance to investigate various plans as expected. Heat loss and heat gain are separately calculated for summer and winter and tabulated in the table accordingly.

Table 5.11. The results for a single block of building for each plan alternative.

| Building | Storey | Exergy Load Summer [W] | Exergy Load Winter [W] | Exergy by Fuel [W] | Exergy Efficiency [%] | Exergy Flexibility Factor [%] |
|---|---|---|---|---|---|---|
| Plan 1 | 4 | 5932.48 | 3322.9 | 2130.5 | 11.2 | 29.0 |
| Plan 2 | 4 | 6842.11 | 4498.0 | 2831.8 | 10.8 | 27.9 |
| Plan 3 | 4 | 5654.66 | 2845.7 | 1817.2 | 11.1 | 28.8 |
| Plan 1 | 8 | 9848.03 | 5424.9 | 3438.1 | 10.9 | 28.3 |

In Table 5.12 results for exergy analysis for solar envelope based design is tabulated. It is clear to be mentioned that the summer exergy load and winter exergy load is in accordance with the expectation that cooling load is higher than the heating load and the exergy efficiencies is in the range of 7 to 11. The higher the building height the larger the exergy loads whereas lower the exergy.

Table 5.12. The results for solar envelop based design.

| Building | Storey | Exergy Load Summer [W] | Exergy Load Winter [W] | Exergy by Fuel [W] | Exergy Efficiency [%] | Exergy Flexibility Factor [%] |
|---|---|---|---|---|---|---|
| Plan 1 | 12 | 16753 | 8330 | 6200 | 10.1 | 39 |
| Plan 1 | 10 | 14048 | 7078 | 5183 | 10.5 | 38 |
| Plan 1 | 8 | 9848 | 5425 | 3438 | 10.9 | 36 |
| Plan 1 | 6 | 8638 | 4575 | 3148 | 11.0 | 33 |
| Plan 1 | 4 | 5932 | 3323 | 2131 | 11.2 | 29 |
| Plan 1 | 2 | 3227 | 2071 | 1113 | 7.4 | 19 |

The exergy efficiency values are in the range of 10.8% to 11.2% and the exergy by fuel values changes from 2845.7 kW to 5424.9kW (Figure 5.55 and Figure 5.56). The exergy load value of the eight-storey plan 1 type building is much higher than the others because of the increased height and volume that cause an increase in the needs of the building regarding the number of housings are doubled. These results are in accordance with the literature as Hepbaşlı (2012) pointed out as the efficiencies of the buildings with LowEx design reaches to 7-8%. On the other hand, the efficiency value of the eight-storey building is smaller than the four-storey building by 0.3% difference (Figure 5.57). This is also an expected result since the increasing transmission lines in energy system and increasing heat loss area gradually decreases the efficiency of the building.

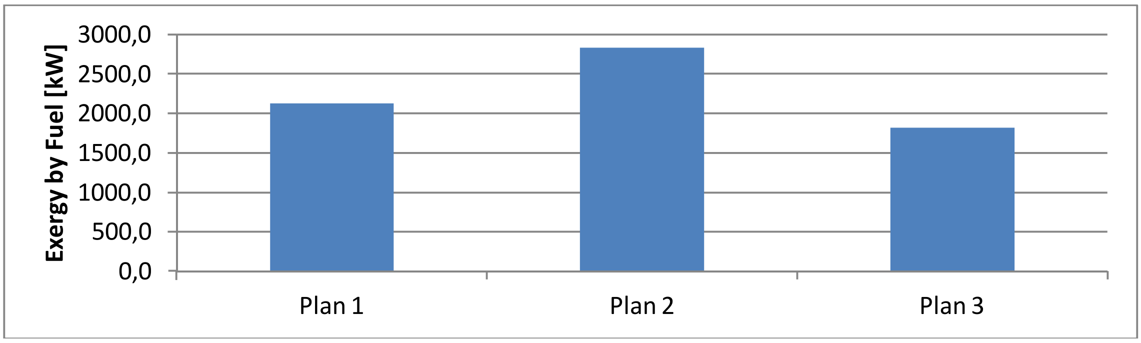


Figure 5.55. The exergy by fuel values of three plans for a building.

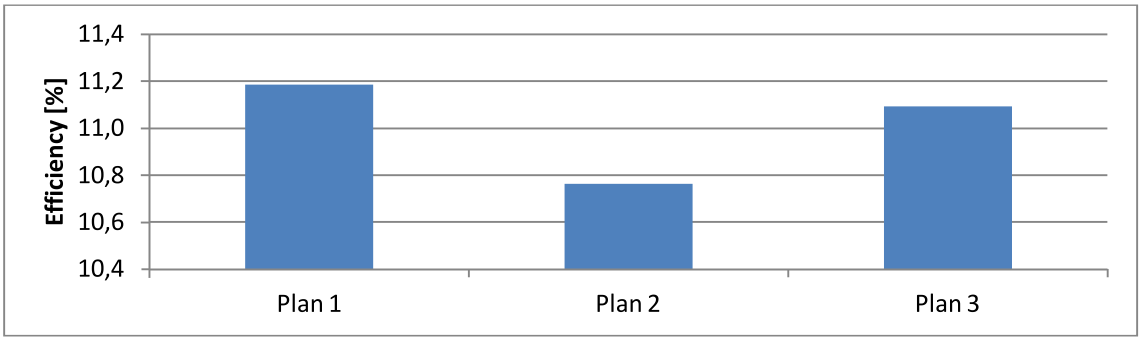


Figure 5.56. The exergy efficiency values of three plans.

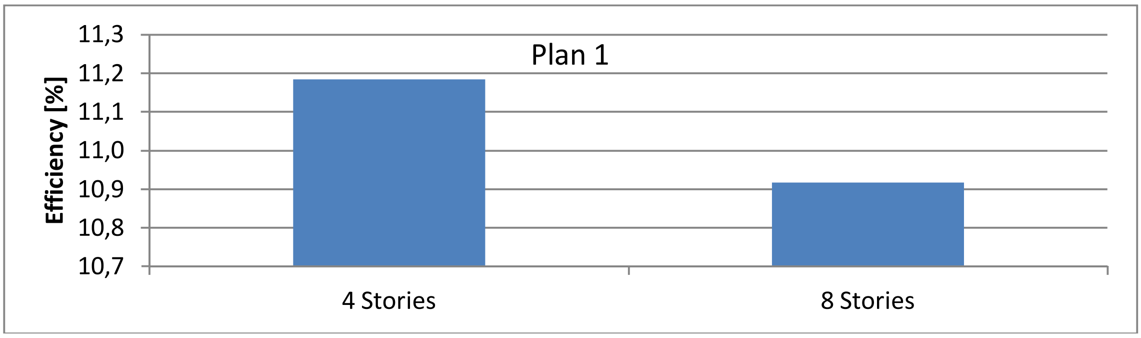


Figure 5.57. The exergy efficiency values of Plan 1.

Table 5.13. The results for a building in Plan 1 for four-storey site with the effect of SEF.

| SEF | Exergy Load Summer [W] | Exergy Load Winter [W] | Exergy by Fuel [W] | Exergy Efficiency [%] | Exergy Flexibility Factor [%] |
|---|---|---|---|---|---|
| 5 | 5902 | 3328.7 | 2141.0 | 11.185 | 29.22 |
| 3 | 5914 | 3326.4 | 2136.8 | 11.229 | 29.14 |
| 0 | 5932 | 3322.9 | 2130.5 | 11.259 | 29.03 |

The effect of the SEF on the exergy load of the plans are tabulated in Table 5.13 for four-storey Plan 1, Table 5.14 for four-storey Plan 2, Table 5.15 for four-storey Plan 3 and Table 5.16 for eight-storey Plan 1. In the site plans 80% of the buildings are shadow free but 10 % of the buildings have 5 SEF and 10 % have 3 SEF. From the tables it is seen that increasing shadow effect increases the exergy load values for all type of plans. This is an expected situation since the decrease in the solar gain increases the need for energy in the building. On the other hand, it is seen that with decreasing SEF the efficiency values increase too (Figure 5.58). This situation is the result of positive effect of the solar gain in building area regarding the efficiency.

Table 5.14. The results for a building in Plan 2 for four-storey site with the effect of SEF.

| SEF | Exergy Load Summer [W] | Exergy Load Winter [W] | Exergy by Fuel [W] | Exergy Efficiency [%] | Exergy Flexibility Factor [%] |
|---|---|---|---|---|---|
| 5 | 6809 | 4504.4 | 2843.5 | 10.764 | 28.09 |
| 3 | 6822 | 4501.8 | 2838.8 | 10.801 | 28.03 |
| 0 | 6842 | 4498.0 | 2831.8 | 10.826 | 27.94 |

Table 5.15. The results for a building in Plan 3 for four-storey site with the effect of SEF.

| SEF | Exergy Load Summer [W] | Exergy Load Winter [W] | Exergy by Fuel [W] | Exergy Efficiency [%] | Exergy Flexibility Factor [%] |
|---|---|---|---|---|---|
| 5 | 5624 | 2851.5 | 1827.7 | 11.092 | 29.01 |
| 3 | 5637 | 2849.1 | 1823.5 | 11.144 | 28.92 |
| 0 | 5655 | 2845.7 | 1817.2 | 11.179 | 28.79 |

Table 5.16. The results for a building in Plan 1 for eight-storey site with the effect of SEF.

| SEF | Exergy Load Summer [W] | Exergy Load Winter [W] | Exergy by Fuel [W] | Exergy Efficiency [%] | Exergy Flexibility Factor [%] |
|---|---|---|---|---|---|
| 5 | 9794 | 5435.2 | 3456.8 | 10.916 | 28.54 |
| 3 | 9816 | 5431.1 | 3449.4 | 10.965 | 28.46 |
| 0 | 9848 | 5424.9 | 3438.1 | 10.998 | 28.33 |

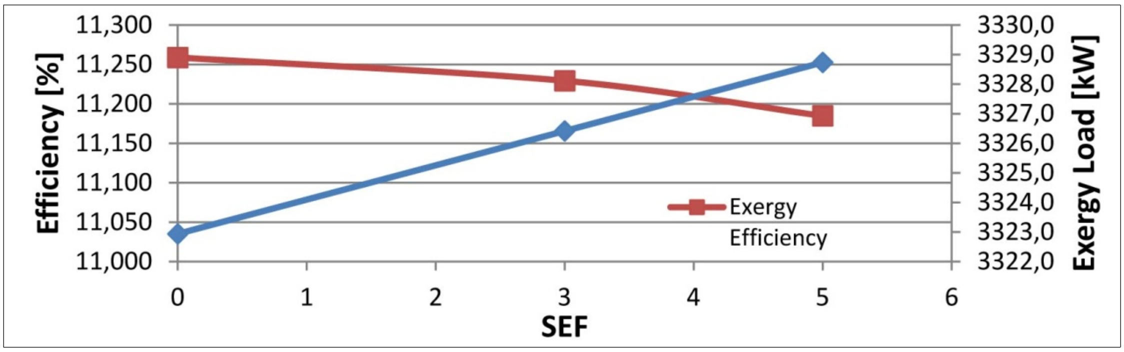


Figure 5.58. Exergy load values with respect to the SEF for Plan 1.

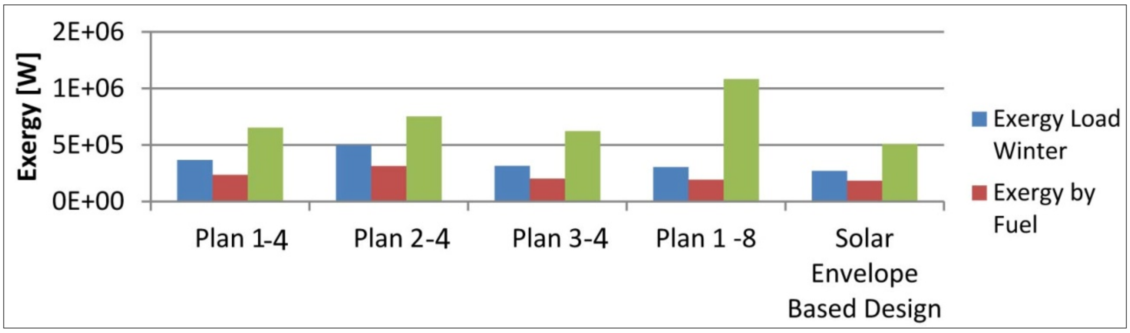


Figure 5.59. Exergy load and exergy by fuel values for the proposed alternatives.

When the total case area is investigated which means that all of the buildings and their relations with each other are taken into account, it is seen that the total exergy load values increases up to 497kW for winter and 752 kW for summer (Table 5.17) in four-storey Plan 2 and 304kW in eight-storey Plan 1. On the other hand, the efficiency values have different tendency from the exergy loads such as the highest exergy efficiency is seen in four-storey Plan 1 and the lowest is seen in four-storey Plan 2 (Figure 5.59). These are also having a similar tendency with the literature while the exergy load is decreasing in buildings in LowEx studies the efficiencies are increasing too (Hepbaşlı 2012). These values are depended mainly on the surface area of the buildings and SEF as well as the plans of the buildings, orientation and the site plan of the case area regarding to these properties.

Table 5.17. The results of the case area.

| | 4-Storey | | | 8-Storey | Solar Envelope Based Design |
|---|---|---|---|---|---|
| | Plan 1 | Plan 2 | Plan 3 | Plan 1 | Plan 1 |
| **Exergy Load Winter [W]** | 367287.5 | 497058.0 | 314595.7 | 304186.6 | 270541.5 |
| **Exergy Load Summer [W]** | 652677.0 | 752850.3 | 622004.75 | 1083182.5 | 507847.0 |
| **Exergy by Fuel [W]** | 235997.3 | 313510.2 | 201411.0 | 193247.6 | 183548.5 |
| **Exergy Efficiency [%]** | 11.235 | 10.806 | 11.151 | 10.972 | 10.420 |
| **Exergy Flexibility Factor** | 29.16 | 28.04 | 28.94 | 28.47 | 32.27 |

## 5.4.3. Comparison, Evaluation, and Interpretation of Findings

When the existing plan and the proposed plan alternatives are compared it is seen that the exergy load value for existing plan is higher 10 times than the new designs. It is the theory that the thesis proposes that the energy efficient design can lead high ratios of energy conservation. In Figure 5.60, the exergy per separate housing unit is shown. It is seen that the best value is in eight-storey Plan 1 type housing with 137W while in existing plan this value lies in the range of 1800W. 8 storey Plan 1's exergy load values are lower than the others mainly because of the general heating systems high performance in high number of housing units. This investigation is carried out per housing unit since the housing unit numbers are different in proposed plan alternatives and the existing situation. So in order to achieve a logical discussion, comparison per housing unit is applied.

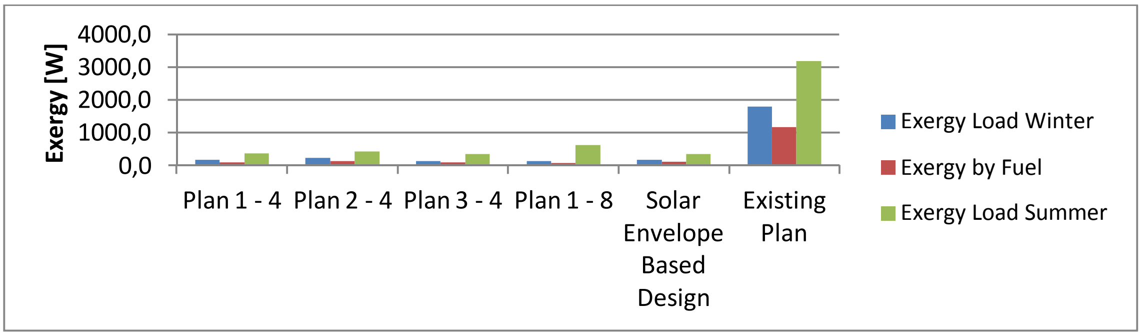


Figure 5.60. Exergy load and exergy by fuel values of proposed alternatives and existing plan.

From cooling loads point of view in summer period, it is seen that the saving is much higher since the exergy load value decreases from 3181 to 616 at large. This is a result of proper airing and use of excellent construction materials especially (Figure 5.60). When the literature values (Hepbaşlı 2012) of cooling loads are investigated it is seen that cooling loads for hot-humid zones are higher than heating loads and it is seen that the results of this study is in accordance with the literature.

Table 5.18. The saving by energy efficient design per housing unit.

| | **4-Storey** | | | **8-Storey** | **Solar Envelope Based Design** | **Existing Plan** |
|---|---|---|---|---|---|---|
| | **Plan 1** | **Plan 2** | **Plan 3** | **Plan 1** | | |
| **Exergy Load Winter [W]** | 166.3 | 225.1 | 142.5 | 137.8 | 184.7961 | 1798.0 |
| **Exergy by Fuel [W]** | 105.4 | 140.0 | 89.9 | 86.3 | 125.37 | 1173.0 |
| **Exergy Load Summer [W]** | 371 | 428 | 353 | 616 | 346.89 | 3181 |

The amount of saved money and greenhouse emissions is shown in Table 5.19 per housing unit in the building block. It is seen that every housing unit saves 799.54 TL in a year by the effect of the energy efficient design. This value is very important for most of the families in Turkey. More important than money, nearly 1.32 tons of greenhouse gas emissions per housing unit also have not been emitted to the atmosphere which is a magnificent contribution to the environment for the sake of sustainable and green future. These values are calculated using the energy price of $0.08 /kW for cost and using reaction stoichiometry calculations with natural gas as fuel in the case area.

Table 5.19. The annual saving by energy efficient design.

| **Conservation Type** | **Conservation Amount (per year)** |
|---|---|
| Exergy Winter [W] | 1631.66 |
| Exergy Summer [W] | 2810 |
| Money [TL] | 799.54 |
| $CO_2$ Emission [kg] | 1332.56 |

The exergy calculations are concluded with determinations of exergy efficiency and exergy loads in addition to the annual conservation of exergy, money and greenhouse gases.

Table 5.20. Design values of existing and proposed plan alternatives.

| | **Existing Building Block** | **Four-Storey Building Block** | **Eight-Storey Building Block** | **Solar Envelop Based Building Block** |
|---|---|---|---|---|
| **Number of Building** | 155 | 137 | 70 | 56 |
| **Housing Unit (number)** | 5320 | 2192 | 2240 | 1464 |
| **Floor Area of Housing Unit ($m^2$)** | 56 $m^2$-150 $m^2$ | 104 $m^2$ and 117 $m^2$ | 117 $m^2$ | 117 $m^2$ |
| **Total Housing Area ($m^2$)** | 54135 | 73980 | 37800 | 30240 |

In the Table 5.20, general features of the existing building block and the proposed design alternatives are summarized. Each energy efficient design alternative has less housing unit than the existing building block. It is seen that when energy efficient design parameters are taken into account such as proper distance allocation among the buildings for sun light purposes lower density building block is needed. In the existing plan the parking area is also larger than the proposed building block because of the high housing unit number. Moreover, the high housing unit number causes a decrease in the green open spaces, sports areas and playground areas.

As it is seen from Table 5.18 the housing unit number is decreased in the alternative design proposals. This result mostly arises from the fact that the spacing between the buildings is increased in energy efficient design that results in a lower density in the built area. On the other hand, when the alternative designs are considered the monotone structure of the plans could be easily seen but this factor is mainly neglected in this study since energy efficiency and conservation is aimed especially by means of increasing solar access in the building blocks. However, a multi-objective study may be carried out considering these factors for future studies.

It is also figured out that the alternative designs propose larger green areas, open spaces and social areas with respect to the existing situation in the area. That is also mostly due to the spacing between the buildings. The alternative building plans has different exergy results as expected. The number of storeys (height of the building), the floor area, area of the openings (doors and windows) and walls are the most effective factors on exergy load and efficiency.

From the energy efficiency point of view, it is seen from the study that when the planning and design is developed considering the energy efficient design parameters the efficiencies considerably increase. That brings us to a position to propose considering these parameters in every planning and design study as well as implementing these on the building and planning acts.

# CHAPTER 6

# CONCLUSION

This dissertation introduces the exergy analysis method into urban planning field in order to find out the amount of energy that can be conserved in a building block when energy efficient design is applied. Two hypotheses are developed: 1. Exergy analysis is a suitable tool for the built environment, and 2. Energy efficient design parameters provide energy saving in the built environment. A case study approach is undertaken in order to test the hypotheses stated above. To achieve this, energy efficient design parameters are investigated through relevant primary sources. The parameters are classified according to the climate regions and depending on the selected parameters new building block plan alternatives are proposed and exergy analysis are conducted for measuring the energy conservation.

This dissertation contributes to the literature by integrating exergy analysis into planning and urban design on the building block scale and taking into account most of the parameters that are effective in the energy performance of the settlement area such as orientation, SEF, floor area, window/door area, and insulation. For this reason, the study is unique in the literature. Such parameters are used in developing energy efficient design alternatives and the exergy analysis method is applied in Mavişehir as a case study. After applying exergy analysis to the area, a result of 1.74% is found in the existing design for exergy efficiency. This shows that there is space for an increase in the exergy efficiency. It is seen that the passive gain from the solar energy is not taken into consideration in the current design of the area. In this study, besides the construction materials, orientation and location properties, solar radiation and wind effects are also taken into account in the exergy analysis. Though various renewable sources can also be used for supplying energy to the area, this is not covered by this study.

In order to increase the energy efficiency in the building block new design alternatives are proposed. Five different alternatives are generated with three different building plans. Three of them are four-storey, one plan is eight- storey and the last plan is designed according to a solar envelope based design that has various storeys of buildings. The results of the exergy analysis of the proposed design alternatives show that the exergy efficiency values increase to 12% from 1.5%. The exergy efficiency is increased considerably and a large amount of energy and money can be conserved through the application of the energy efficient design. The results also show that the annual exergy load of a single housing unit is decreased from 1800W to 137W for winter and 3180W to 346 W in summer.

When considering these results, it proves that site plan decisions and energy conservation are interrelated and essential for maximizing passive system effects and minimizing energy usage. Efficient use of energy and use of passive systems are key factors of sustainable urban areas. For these reasons architects, landscape architects, city planners, urban designers and other actors that are to play role in the construction and design of the urban area must pay attention to these topics.

In looking at a global scale, large amounts of energy are used in buildings. For this reason, planners and architects must keep this in mind and should produce living areas that have high standards of construction. This should not only be with a luxury perspective but also from the point of view for energy efficiency. The application of this thought must start from the beginning of the design phase and continue until the project ends. This approach, with its increased efficiency, is also beneficial from an environmental perspective because it decreases the emissions that arise from the heating and cooling systems of the buildings.

Sustaining the needs for housing in society continues while not underestimating the important perspective of energy. In order to form a sustainable settlement the energy demands must be optimized for housing units, building blocks and neighborhood scales. This is done by applying energy efficient design parameters from the initial steps of the design. Especially for mass housing projects, more flexible design strategies must be used that eases the design. In mass housing areas, there is more possibility of designing freely without restrictions. Designers may use solar energy and other passive energies when considering comfort conditions, energy conservation, etc.

It is recommended that this analysis technique be applied to the designated urban renewal areas in Turkey (and elsewhere) for the sake of energy conservation and cost reduction in operating costs of these areas. These approaches cannot be left to the goodwill of the planners and architects alone. Those responsible for regulations of planning and design should also take this into account to reach this aim. Furthermore, to these the building acts and regulations can be redesigned to include the exergy concept since this study proves that these considerations of exergy and energy efficient design parameters are beneficial for the built environment. The increment in the passive gain must be guaranteed by sustaining proper regulation and the distance between the buildings. Similarly the orientation of the project selected must be enforced in order to decrease shadow lengths and increasing passive gain.

Finally, a number of important limitations needed to be considered for this dissertation. First, some energy efficient design parameters could not be used in the exergy analysis measuring. For example, the analysis could not use, the effects of open space, planting elements, and reflective and impervious ground covering on roads, sidewalk, parking area and so on. This situation arises because the effects of these parameters are well known, but the quantities of the effects for these parameters are hard to prove and contain in the study. Besides this, the effect of the surrounding built-up area in Mavişehir is not an effective factor on the analysis; however, the surrounding built-up area may cause a microclimate effect on the case area. From an exergy point of view these effects are much harder to analyze in a consistent manner. The use of landscape and planting elements, and the ground cover elements of roads and parking area are however taken into account in the development process of design alternatives. Second, in this dissertation, only passive system renewable energy resources are integrated into the design phase. The capabilities of the area from other renewables are not introduced since this study mainly aims to show the exergy performance of the energy efficient design.

In conclusion, it is recommended that further research can be undertaken in the following areas: First of all, an experimental study may be conducted considering all passive renewable energy systems in an urban area. Along with this, the effect of the parameters that are not included in this study should also be introduced to the calculations and measuring these effects in a true manner. Secondly, the local active renewable energy resources (solar energy, wind energy, geothermal energy, bio mass energy etc.) can be investigated and then integrated into the design phases. Therefore, from the energy efficient design level, the design will come to a sustainable level. Finally, this dissertation focuses on a hot-humid region, so further studies should be conducted which include other climate regions.

As a result of this study, it proves that exergy analysis is beneficial for city planning. It will ease and help planners to understand the energy concepts and possibilities that are hidden under the energy analysis. In addition, by applying an energy efficient design to the selected building block 1631 W of energy can be conserved in the winter and 2810 W in the summer period for a housing unit. With this energy conservation, 799.54 TL per housing unit is saved annually, which comes up to 12792.64 TL for a block of buildings. More important than that 1332.56 kg of emission gases per housing unit, or 21320.96 kg for a block of buildings is not being released into the atmosphere. This, results in the formation of a more sustainable neighborhood. When the total area is taken into account, the exergy efficiency is reached up to 11.23% while EFF is 29.16. The Exergy by Fuel Value is 235.997 kW with Summer Exergy Load of 652.667kW and Winter Exergy Load of 367.287 kW. These are the main indications of the importance of the study and the final results that are reached through the exergy analysis.

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# APPENDIX A

# SUMMARY TABLE OF THE LITERATURE

Table A.1. Summary of the literature in terms of parameters and findings

| Author | Climate Region & Scale | Design Parameters | Parameters of Case Study | Findings |
|---|---|---|---|---|
| Ok<br>1988 | Mild-humid<br>&<br>Building Block Scale | A. Climate<br>1. Solar radiation<br>2. Wind<br>B. Physical parameters<br>1. Topography<br>2. Orientation<br>3. Planting<br>4. Form of the settlement<br>5. Density of the settlement<br>6. Location of the buildings<br>7. Building form | The parameters are investigated using 16 different orientations with 22,5 °angle. | • The amount of solar access and the power of solar radiation decreases with increasing building density.<br>• Buildings having 1:1 form factor has minimum buildings having 1:1,38 have maximum solar radiation<br>• When buildings having same height and building form are investigated the space between the buildings positively effects the solar radiation.<br>• Buildings having N-S direction must have a spacing of 2-3h, NW-SE direction with 1.5-2.5h spacing, E-W direction with 0.5-1.5h for a better solar access. |

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Table A.1. (cont.)

| Author | Climate Region & Scale | Design Parameters | Parameters of Case Study | Findings |
|---|---|---|---|---|
| Aksoy 2002 | Mild-dry & Building Scale | A. Physical Environment Design Parameters<br>1. Solar radiation<br>2. Temperature<br>3. Humidity<br>4. Wind<br>B. Building Design Parameters<br>1. Orientation of building<br>2. Building form<br>3. Building envelope<br>4. Location of the building to other buildings | • 9 different orientations starting from north.<br>• Square or rectangular forms; building form factors: 1/1, 2/1, 1/1<br>• simple geometric facades<br>• ratio of surface transparency; %15, %20, %25<br>• uninsulated, insulated,2.5 cm, 5 cm, 5 cm, 10 cm,15 cm | • Orientation of building features of building envelope, insulation materials are most important parameters for annual heating energy.<br>• A 1/1 building forms factor is most advantageous for annual heating energy<br>• Buildings that face south is more advantageous then the others from a heating point of view.<br>• Insulation thickness is inversely proportional with the heating load. Insulation thickness change are effective in between 2.5 to 10 cm<br>• Transparency ratio must be below 15% for minimum heating load, larger values increases heating load. |

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Table A.1. Summary of the literature in terms of parameters and findings (**cont.**)

| **Author** | **Climate Region & Scale** | **Design Parameters** | **Parameters of Case Study** | **Findings** |
|---|---|---|---|---|
| Tokuç 2005 | Hot-humid & Building Scale & Building Block Scale | A. Settlement Scale<br>1. Topography<br>2. Orientation<br>3. Distance between buildings<br>4. Design of open spaces<br>B. Volumetric Design Scale<br>1. Building form<br>2. Characteristic of facades<br>C. Spatial Scale<br>D. Building element design scale | Investigation of design parameters through user survey. | Solar energy factor is not taken into account in design period. |
| Çalışkan 2007 | Mild-humid & Building Block Scale | A. Conservation of natural resources<br>1. Conservation of energy<br>• Optimum orientation<br>• Insulation<br>• Using high performance window<br>• Using renewable energy resources<br>• Compact building design<br>• Energy efficient land-use<br>• Landscape design for energy conservation<br>2. Conservation of water<br>3. Conservation of raw materials<br>B. Prevention of waste and pollution<br>C. Environment design for suitable human health | • Building block design with 5 block with two-storey building<br>• Building with 90m2 floor area with simple geometry<br>• South facade of the buildings are designed in order to supply equal solar access<br>• Blocks are placed in the field in order to allow wind access through the buildings.<br>• Buildings are oriented with a 30 ° from the south towards east. | |

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Table A.1. (cont.)

| **Author** | **Climate Region & Scale** | **Design Parameters** | **Parameters of Case Study** | **Findings** |
|---|---|---|---|---|
| Ozmehmet 2005 | Hot-humid & Building Scale | 1. Location of the building<br>2. Building form<br>3. Spatial organization of the building<br>4. Materials | Investigation of parameters in building scale;<br>• Natural aeration and solar access in used<br>• Climate properties are not directly taken into account<br>• Ecological and healthy materials are not selected. | • |
| Soysal 2008 | Mild-dry & Building Block Scale | A. Environmental Parameters<br>1. Topography<br>2. Climate<br>i. Solar radiation<br>ii. Wind<br>iii. Temperature<br>iv. Humidity<br>3. Planting<br>4. Effects of closed built environment<br>B. Structural Parameters<br>1. Orientation of the building<br>2. Building form<br>3. Structure of built environment<br>4. Distance between buildings and building height<br>5. Materials of building envelope<br>6. Shape factor of building | • All design parameters investigated through case study | • The positions of the buildings and the relations of the buildings with each other must be taken into account in the early steps of design.<br>• Close environment and buildings must not be neglected.<br>• The most advantageous buildings are in a north-south direction having the living room and kitchen facing south and bedrooms facing north.<br>• Window openings must be maximized southward to let solar access through the apartment. |

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Table A.1. (cont.)

| Author | Climate Region & Scale | Design Parameters | Parameters of Case Study | Findings |
|---|---|---|---|---|
| Canan 2008 | Hot-dry & Neighborhood Scale | A. Building Design Parameters<br>1. Orientation of building<br>2. Location of building<br>3. Building form<br>4. Building envelope<br>B. Microclimate and built environment<br>C. Planting | Attached and detached neighborhood | • Rectangular shapes must be chosen instead of square form for increasing solar radiation.<br>• The building act must be reformed to increase solar energy gain.<br>• Solar envelope is used as helper element during location of buildings and building groups<br>• Urban design and building design phases are taken into account in harmony<br>• Blocks of building can involve different size and features housing units; studios, duplex, triplex housing units can be designed on tap layer of the block. |

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Table A.1. (cont.)

| Author | Climate Region & Scale | Design Parameters | Parameters of Case Study | Findings |
|---|---|---|---|---|
| Karaca 2008 | Cold<br>Mild-dry<br>Mild-humid<br>Hot-dry<br>Hot-humid<br>&<br>Neighborhood Scale | A. Parameters based on physical environment<br>1. Climate<br>i. Temperature<br>ii. Wind<br>iii. Solar radiation<br>iv. Humidity<br>v. Cloudy or sunny weather<br>2. Topography and location<br>3. Planting<br>B. Parameters based on technical and technological developments<br>1. Energy production and conservation based on renewable energy sources<br>2. Prevention of waste and pollution<br>3. Water use efficiency and re-use of water<br>C. Parameters based on design and constructive solution<br>1. Orientation and shadow length (the role of shadow length determining the distance between buildings)<br>2. Building form<br>3. Building envelope<br>4. Building materials | • Totally 48 different mass-housing projects<br>• Each project is investigated based on energy efficient chart that is created energy efficient design parameters. | • Almost all design parameters not use during design period in investigated projects.<br>• Climate data are not taken into account in all investigated projects.<br>• Topography and location design parameters are taken into account in recent projects.<br>• Local planting texture are practice on planting design period<br>• Technical and technological developments (especially solar and wind energies) are not use in investigated projects.<br>• Waste recycling and re-use of water processes are not taking into account in investigated projects.<br>• Local and natural materials are not into account in investigated projects.<br>• Spacing of the buildings is taken into account in mostly projects.<br>• Insulation parameter is taken into account in all investigated projects.<br>• Energy efficient design parameters should be taken into account during housing production period.<br>• The design parameters should be defined based on climate regions. The design parameters should be flexible.<br>• Climate region characters and microclimate should be well-analyzed. |

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Table A.1. (cont.)

| Author | Climate Region & Scale | Design Parameters | Parameters of Case Study | Findings |
|---|---|---|---|---|
| Hisarlıgil 2009 | Mild-dry & Building Scale | A. Climate Features<br>1. Psychometric analysis<br>2. Heating and cooling degree hours<br>3. Optimum orientation<br>B. Energy Efficient Building<br>1. Orientation of building<br>2. Location of building<br>3. Building form<br>4. The Area/Volume ratio<br>5. Window, wall ratio and therm transmittance coefficients<br>6. Heating and cooling loads<br>C. Energy Efficient Building Block<br>1. Building block form<br>2. Size of the building block<br>3. Perimeter/Area ratio<br>4. FAR (Floor Area Ratio)<br>5. PAR (Plot Area Ratio)<br>6. Planting<br>7. Heating and cooling loads<br>8. Microclimate features (coolest ar hottest periods)<br>D. Energy Efficient Settlement<br>1. Heating and cooling loads<br>2. Built-up area<br>3. Location of building blocks | | • Depth and height of the buildings must be 12m in east – west direction facing south is optimum for solar gain.<br>• For building block the ration of FIR/FAR must be increased for supplying homogeny solar radiation through the buildings.<br>• The surface area-volume ratio is inversely proportional with the cooling load and directly proportional with the heating load.<br>• Optimum orientation and decrease of windows are some of the passive techniques used to decrease the cooling and heating loads.<br>• Increases in the building stories the heating loads are decreasing and cooling loads are increasing for a housing unit.<br>• 4. Story buildings are found as optimum for maximum effect on solar gain and wind effect.<br>• In the formation of the building blocks the prevailing wind directions must be taken into account in both summer and winter. |

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Table A.1. (cont.)

| Author | Climate Region & Scale | Design Parameters | Parameters of Case Study | Findings |
|---|---|---|---|---|
| Ovalı 2009 | Hot-humid & Neighborhood | A. Energy Conservation<br>1. Parameters based on physical environment<br>i. Topography<br>ii. Climate<br>• Solar radiation<br>• Temperature<br>• Humidity<br>• Wind<br>2. Organization of physical environment<br>i. Location of the building<br>ii. Orientation of the building<br>iii. Building form<br>iv. Distance between the buildings<br>v. Building envelope and insulation<br>vi. Natural ventilation and solar control<br>vii. Spatial organization<br>viii. Building material<br>B. Parameters based on increasing energy gain<br>1. Passive method<br>i. Passive heating<br>ii. Passive cooling<br>2. Active method<br>3. Hybrid (passive + active) method | • All design parameters are investigated through the case study.<br>• It is seen that the case study neighborhood (Kayaköy-Mugla) is designed with harmony on all parameters. | • Decreasing the negative effect of the humidity in the hot-humid climates is an important design parameter.<br>• For reaching optimum efficiency comfort aeration, corresponding aeration roof pooling methods can be selected for application.<br>• Passive cooling strategies are favored. |

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Table A.1. (cont.)

| **Author** | **Climate Region & Scale** | **Design Parameters** | **Parameters of Case Study** | **Findings** |
|---|---|---|---|---|
| Barreiro et al. 2009 | Mild-dry & Neighborhood Scale | A. Urban planning<br>1. Regulations<br>2. Climate<br>3. Land uses<br>B. Building<br>1. Building typology (volume)<br>2. Parcel (form, dimension, orientation)<br>3. Distance between buildings<br>4. Percentage of the glazing<br>5. Shading elements<br>C. Other urban elements<br>1. Street network<br>2. Open spaces<br>D. Building solutions<br>1. Façade<br>2. Roof<br>3. Ground floor slab<br>4. Glazing<br>5. Vegetation | According to the parameters 31 indicators are defined. | It is indicated that the parameters of energy efficiency has greatly effect on the energy consumption in urban area and must be evaluated through the early steps of urban design. |

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# APPENDIX B

# LOWEX EXERGY OPTIMISED BUILDING DESIGN

Table B.1. Lowex exergy optimised building design

| Pre-design sheet for an exergy optimised building design IEA ECBCS Annex 37 Steady state calculations for heating case Version 2.3 | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Object:** | | *The ZUB Office Building, IEA Annex 37 Demoproject* | | | | | |
| 1 | **1. Project data, boundary conditions** | | | | | | |
| 2 | Volume (inside) [m³] | V = | *6264* | | | | |
| 3 | Net floor area [m²] | $A_N$ = | *522* | | | | |
| 4 | Indoor air temperature [°C] | $q_i$ = | *21* | | | | |
| 5 | Exterior air temperature [°C] | $q_e$ = | *10.9* | = $q_{ref}$ Reference temperature | | | |
| 6 | **2. Heat losses** | | | | | | |
| 7 | **2.1 Transmission losses $F_T$[W]** | | | | | | |
| 8 | Building part | Symbols | Area $A_i$ | Thermal transmittance $U_i$ | $U_i$ * $A_i$ | Temperature-correction-factor $F_{xi}$ | $U_i$ * $A_i$ * $F_{xi}$ |
| | | | [m²] | [W/(m²K)] | [W/K] | [ - ] | [W/K] |
| 9-12 | Exterior wall | EW 1 | *1002.0* | *0.50* | *501.00* | 1 | *501.00* |
| 13-16 | Window - Door | W 1 | *133.6* | *0.90* | *156.24* | 1 | *156.24* |
| 17 | | | | | | | |
| 18-19 | Roof | R 1 | *522.00* | *0.27* | *140.94* | 1 | *140.94* |
| 20 | Upper story floor | | | | | | |
| 21 | Wall to roof rooms | | | | | | |

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Table B.1. (cont.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 22-24 | | | | | | | |
| 25 | Walls and floors to unheated rooms | | | | | | |
| 26 | | | | | | | |
| 27 | Floors to ground. Areas of unheated cellar to ground | G 1 | *522.00* | *0.27* | *140.94* | 0.6 | *84.56* |
| 28 | | | | | | | |
| 29 | | | | | | | |
| 30 | | | | | | | |
| 31 | | | | | | | |
| 32 | | **S $A_i$ = A =** | *2219.60* | **Specific transmission heat loss** | | **S $U_i$ * $A_i$ * $F_{xi}$ =** | *882.74* |
| 33 | Transmission heat losses [W] | $F_T$ = S ($U_i$ * $A_i$ * $F_{xi}$) * ($q_i$ - $q_e$) | | | | | |
| | | $F_T$ = | *882.74 ** | *10.10* | | **$F_T$ =** | *8.915.71* |
| 34 | **2.2 Ventilation heat losses $F_V$ [W]** | | | | | | |
| 35 | Air exchange rate [ach/h] | $n_d$ = | *0.3* | | | | |
| 36 | Heat exchanger efficiency [-] | $h_V$ = | *0.8* | | | | |
| 37 | Ventilation heat losses [W] | $F_V$ = (cp * r * V * $n_d$ * (1-$h_V$)) * ($q_i$ - $q_e$) | | | | | |
| | | $F_V$ = | *125.91 ** | *10.10* | | **$F_V$ =** | *1.271.65* |
| 38 | **3. Heat gains** | | | | | | |
| 39 | **3.1 Solar heat gains $F_s$ [W]** | | | | | | |
| 40 | Window frame fraction [-] | $F_f$ = | *0.18* | | | | |
| 41 | Orientation | | Solar radiation $I_{s,j}$ | | Window area $A_{W,j}$ | Total trans-mittance gj | $I_{s,j}$ * (1-$F_f$) * 0.9 * 0.9 *$A_{W,j}$ * $g_j$ [1)] |
| | | | [W/m²] | | [m²] | [ - ] | [W] |
| 42 | south-east to south-west | | 25 | | *72.80* | *0.50* | *604.42* |
| 43 | | | | | | | |

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Table B.1. (cont.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 44 | north-west to north-east | | 10 | | *68.80* | *0.50* | *228.48* |
| 45 | | | | | | | |
| 46 | other directions | | 15 | | | *0.50* | |
| 47 | | | | | | | |
| 48 | Dormer window with slope < 30° | | 5 | | | | |
| 49 | Solar heat gains: | $F_s$ = S ($I_{s,j}$ * (1-$F_f$) * $A_{W,j}$ * $g_j$) | | | | **$F_s$ =** | *832.91* |
| 50 | **3.2 Internal Heat Gains $F_i$ [W]** | | | | | | |
| 51 | Number of occupants [-]: | $no_o$ = | *64.00* | | | | |
| 52 | Internal gains of occupants [W]: | $F_{i,o}$ = | $no_o$ | * $F''_{i,o}$ | | | |
| | | $F_{i,o}$ = | *64.00* | * *80.00* | | **$F_{i,o}$ =** | *5.120.00* |
| 53 | Spec. internal gains of equipment [W/m²]: | $F''_{i,e}$ = | *1.00* | | | | |
| 54 | Internal gains of equipment [W]: | $F_{i,e}$ = | $F''_{i,e}$ | * $A_N$ | | | |
| | | $F_{i,e}$ = | *1.00* | * *522.00* | | **$F_{i,e}$ =** | *522.00* |
| 55 | **4. Other uses** | | | | | | |
| 56 | Spec. lighting power [W/m²]: | $p_l$ = | *0.2* | | | | |
| 57 | Lighting power [W]: | $P_l$ = $p_l$ | * $A_N$ | = | $F_{i,l}$ | | |
| | | $P_l$ = | *0.20* | * *522.00* | | **$P_l$ =** | *104.40* |
| 58 | Spec. ventilation power [Wh/m³]: | $p_v$ = | *0.1* | | | | |
| 59 | Ventilation power [W]: | $P_v$ = pv | * V * | $n_d$ | | | |
| | | $P_v$ = | *0.10* | * *6.264.00* | * *0.30* | **$P_v$ =** | *187.92* |
| 60 | **5. Heat demand $F_h$ [W]** | | | | | | |
| 61 | Heat demand [W]: | $F_h$ = ($F_T$ + $F_V$) - ($F_s$ + $F_{i,o}$ + $F_{i,e}$ + $F_{i,l}$) | | | | | |
| | | $F_h$ = | *10.187.37* | *6.579.31* | | **$F_h$ =** | *3.608.06* |
| 62 | Specific heat demand [W/m²] | $F''_h$ = | $F_h$ / $A_N$ | | | | |
| | | $F''_h$ = | *3.608.06* / | *522.00* | | **$F''_h$ =** | *6.91* |

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Table B.1. (cont.)

| | | | | | |
|---|---|---|---|---|---|
| 63 | **6. Heat production and emission** | | | | |
| 64 | Generation / Conversion: | | District heat | Efficiency $h_G$ [-] | *0.89* |
| | | | | Primary energy factor source $F_P$ [-] | *0.50* |
| | | | | Quality factor of source $F_{q,S}$ [-] | *0.10* |
| | | | | Max. supply temperature $q_{S,max}$ [°C] | *100.00* |
| | | | | Auxiliary energy $p_{aux,ge}$ [W/kW$_{heat}$] | *0.01* |
| | | | | Auxiliary energy $p_{aux,ge,const}$ [W] | |
| | | | | Part. environmental energy $F_{renew}$ [-] | |
| 65 | Storage: | | No storage | Heat loss / efficiency $h_S$ [-] | *1.00* |
| | | | | Auxiliary energy $p_{aux,S}$ [W/kW$_{heat}$] | |
| | | | | Solar fraction $F_S$ [-] | |
| 66 | Distribution system: | Boiler position | Inside envelope | | |
| | | Insulation | Good insulation | | |
| | | Design temperature | no distribution | Heat loss / efficiency $h_D$ [-] | *0.98* |
| | | Temperature drop | no distribution | Auxiliary energy $p_{aux,D}$ [W/kW$_{heat}$] | |
| 67 | Emission system: | | Slab heating | Inlet temperature $q_{in}$ [°C] | *28.00* |
| | | | | Return temperature $q_{ret}$ [°C] | *22.00* |
| | | | | Auxiliary energy $p_{aux,E}$ [W/kW$_{heat}$] | *2.00* |
| | | | | Max. heat emission $p_{heat,max}$ [W/m²] | *40.00* |
| | | | | Heat loss / efficiency $h_E$ [-] | *0.99* |
| 68 | DHW production system: | | No DHW production | DHW demand $V_W$ [l/pers·d] | |
| | | | | Efficiency $h_{G,DHW}$ [-] | |
| | | | | Primary energy factor source $F_{P,DHW}$ [-] | |
| | | | | Quality factor of source $F_{q,S,DHW}$ [-] | |
| 69 | **7. Results of exergy calculation** | | | | |

**(cont. on next page)**

Table B.1. (cont.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 70 | Quality factor room air [-]: | $F_{q,room} = 1 - T_e / T_i$ | | | | | |
| | | $F_{q,room} =$ | *0.03* | | | $\mathbf{F_{q,room}} =$ | *0.03* |
| 71 | Exergy load room [W]: | $Ex_{room} = F_h * F_{q,room}$ | | | | | |
| | | $Ex_{room} =$ | *3.608.06* | * *0.03* | | $\mathbf{Ex_{room}} =$ | *123.89* |
| 72 | Heating temperature [°C]: | $q_{heat} =$ Dlogq /2 + $q_i$ | | | | | |
| | | $q_{heat} =$ | *1.54* | * *21.00* | | $\mathbf{q_{heat}} =$ | *22.54* |
| 73 | Quality factor air at heater [-]: | $F_{q,heater} = 1 - T_e / T_{heat}$ | | | | | |
| | | $F_{q,heater} =$ | *0.04* | | | $\mathbf{F_{q,heater}} =$ | *0.04* |
| 74 | Exergy load at heater [W]: | $Ex_{heat} = F_h * F_{q,heater}$ | | | | | |
| | | $Ex_{heat} =$ | *3.608.06* * | *0.04* | | $\mathbf{Ex_{heat}} =$ | *142.05* |
| 75 | Heat loss emission [W]: | $F_{loss,E} = F_h * (1/h_E-1)$ | | | | | |
| | | $F_{loss,E} =$ | *3.608.06* * | *0.01* | | $\mathbf{F_{loss,E}} =$ | *36.45* |
| 76 | Auxiliary energy emission [W]: | $P_{aux,E} = p_{aux,E} * F_h$ | | | | | |
| | | $P_{aux,E} =$ | *0.00* * | *3.608.06* | | $\mathbf{P_{aux,E}} =$ | *7.22* |
| 77 | Exergy demand emission [W]: | $DEx_{emis} = \{ (F_h+F_{loss,E})/(T_{in} - T_{ret})\} * \{(T_{in} - T_{ret}) - T_{ref} * \ln (T_{in} / T_{ret} )\}$ | | | | | |
| | | $DEx_{emis} =$ | *607.42* * | *0.28* | | $\mathbf{DEx_{emis}} =$ | *172.24* |
| 78 | Heat loss distributon [W]: | $F_{loss,D} = (F_h+F_{loss,E}) * (1/h_D-1)$ | | | | | |
| | | $F_{loss,D} =$ | *3.644.51* * | *0.020408163* | | $\mathbf{F_{loss,D}} =$ | *74.38* |
| 79 | Auxiliary energy distribution [W]: | $P_{aux,D} = p_{aux,D} * (F_h+F_{loss,E})$ | | | | | |
| | | $P_{aux,D} =$ | * | *3.644.51* | | $\mathbf{P_{aux,D}} =$ | |
| 80 | Exergy demand distribution [W]: | $DEx_{dis} = \{ F_{loss,D} / DT_{dis} \} * \{( DT_{dis} - T_{ref} * \ln ( T_{dis} / T_{dis} - DT_{dis} )\}$ | | | | | |
| | | $DEx_{dis} =$ | *#SAYI/0!* | | | $\mathbf{DEx_{dis}} =$ | |
| 81 | Heat loss storage [W]: | $F_{loss,S} = (F_h+F_{loss,E}+F_{loss,D}) * (1/h_S-1)$ | | | | | |
| | | $F_{loss,S} =$ | *3.718.89* * | | | $\mathbf{F_{loss,S}} =$ | |

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Table B.1. (cont.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 82 | Auxiliary energy storage [W]: | $P_{aux,S}$ = $p_{aux,S}$ * $(F_h+F_{loss,E}+F_{loss,D})$ | | | | | |
| | | $P_{aux,S}$ = | * | *3.718.89* | | **$P_{aux,S}$ =** | |
| 83 | Exergy demand storage [W]: | $DEx_{stor}$ = { $F_{loss,S}$ / $DT_{sto}$ } * { $DT_{sto}$ - $T_{ref}$ * ln ( $T_{dis}$ + $DT_{dis}$ / $T_{dis}$ + $DT_{dis}$ - $DT_{sto}$ )} | | | | | |
| | | $DEx_{stor}$ = | | | | **$DEx_{stor}$ =** | |
| 84 | Req. energy of generation [W]: | $F_{ge}$ = $(F_h+F_{loss,E}+F_{loss,D}+F_{loss,S})$ * $(1-F_S)$ / $h_B$ | | | | | |
| | | $F_{ge}$ = | *3.718.89* * | *1.00* / | *0.89* | **$F_{ge}$ =** | *4.178.52* |
| 85 | Auxiliary energy generation [W]: | $P_{aux,ge}$ = $p_{aux,ge}$ * | | | | | |
| | | $P_{aux,ge}$ = | *0.00* * | *3.718.89* | + | **$P_{aux,ge}$ =** | *0.04* |
| 86 | Exergy load generation [W]: | $Ex_{ge}$ = $F_{Ge}$ * $F_{q,S}$ | | | | | |
| | | $Ex_{ge}$ = | *4.178.52* * | *0.10* | | **$Ex_{ge}$ =** | *417.85* |
| 87 | DHW energy demand [W] | $P_W$ = $V_W$ * $c_p$ * r * DT * $no_o$ / $h_{G,DHW}$ | | | | | |
| | | $P_W$ = | | * | / | **$P_W$ =** | |
| 88 | Exergy load plant [W]: | $Ex_{plant}$ = $(P_I+P_V)$ * $F_{q,electricity}$ + $P_W$ * $F_{q,s,DHW}$ | | | | | |
| | | $Ex_{plant}$ = | *292.32* + | | | **$Ex_{plant}$ =** | *292.32* |
| 89 | Req. primary energy input [W]: | $E_{prim,tot}$ = $F_{ge}$ * $F_P$ + $(P_I+P_V+SP_{aux})$ * $F_{P,electricity}$ + $P_W$ * $F_{P,DHW}$ | | | | | |
| | | $E_{prim,tot}$ = | *2.089.26* + | *898.72* + | | **$E_{prim,tot}$ =** | *2.987.98* |
| 90 | Add. renew. energy input [W]: | $E_{renew}$ = $F_{ge}$ * $F_{renew}$ + $E_{environment}$ | | | | | |
| | | $E_{renew}$ = | | | | **$E_{renew}$ =** | |
| 91 | Total exergy input [W]: | $Ex_{tot}$ = $F_{ge}*F_P*F_{q,S}+(P_I+P_V+SP_{aux})*F_{P,elec}*F_{q,elec}+P_W*F_{P,DHW}*F_{q,S,DHW}+E_{renew}*F_{q,renew}$ | | | | | |
| | | $Ex_{tot}$ = | *1.107.65* + | + | | **$Ex_{tot}$ =** | *1.107.65* |
| | [1] 0.9 for shading and 0.9 for not orthogonal radiation | | | | | | |
| | **Results in key figures** | | | | **total** | **per Area** | **per Volume** |
| | Energy input (primary and renewable energy + internal and solar gains) | | | | 9567.29 W | 18.33 W/m² | 1.53 W/m³ |
| | Energy quality of envelope (heat demand + internal and solar gains) | | | | 10187.37 W | 19.52 W/m² | 1.63 W/m³ |
| | Total exergy system efficiency (exergy demand room / total exergy input) | | | | 0.111847 | | |

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Table B.1. (cont.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Exergy flexibility factor (exergy demand emission / total exergy input) | | | | 0.290261 | | |
| | | | **Exergy load [W]** | **Exergy by fuel [W]** | **Exergy Efficiency [-]** | **Energy Efficiency [-]** | |
| Shadow Effect Factor | 0 | | 1107.65 | 710.17 | 11.18473073 | 29.0261371 | |
| **Results of the calculation:** | | | Cooling load | 5932.48488 | Summer Temp | 26.8 | |

# VITA

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